Apologies all round

It seems to be apologies all round this editorial. Firstly I apologise to those who came to the conference, because this issue is devoted to reporting what occurred there, though at times you may wonder. I apologise to those who didn't get there for failing to put into words all we learnt from the more than 500 slides and photographs we were shown. I can only remind you that there is only one way of finding out what can be learnt at conference - come to it. John Wright's notes on the conference at least provide a counterbalance to my more formal report of the proceedings, and between the two you should be able to gain an idea of just how good a conference it was.

I'm glad to be able to include the response to John Saunderson's challenging article in the last issue, though I was a little disappointed with the quality of some of it, as you may gather from certain caustic comments I have made to them. Still, keep the letters coming - I promise not to stick my barbs into everything.

And my apologies for some rather late branch reports, though this time the only one I can take the blame for is that from Pat Tye, which I returned so that Pat could provide us all with a field guide to one of the prettiest areas of England. I hope you consider it worth the wait. The delayed Irish report is occassioned by the fact that they are running it again next year, and wanted the publicity (see the newsletter for details).

Which leads nicely into another point that might be of special interest to new members - you've got to get your name in early for repeated field trips as they are often offered to the participants of the last trip first, leaving very few places for those who have just arrived. Which is a pity in a way as it restricts the number of trips available to the new people, though it has the advantage of promoting friendships and allowing areas to be studied in depth. Any rate, you can't have my place in Wales next year, I booked it at conference. You've got to be in the right place at the right time with the OUGS. See you all at the AGM!

Martin Bryan

Thoughts of Chairman ....

Graded Bedding Results of summer school assesments?

Absolute Age As given by participants of summer school, conference, etc. ±15 years

Accessary Minerals Fluids which facilitate the flow of primary alcohol

Accomodation Structures Very rare occurrences. Definitely not to be confused with beds at summer school or conference

Acid Rock Sold at hippie seaside resorts - assorted flavours eg pot

Automorphic Term used to describe non-starting vehicles at end of a week of non-use at summer school

Balled-up Structure See the dictionary of geology, it does exist! Causes - slumping and collapse give rise to local deformation of the layer whilst in an unconsolidated state!!

Basement Complex Route to late-night retreat at Durham

Bedding-plane A surface parallel to the surface of deposition, which may or may not have a physical expression (*Penguin Dictionary of Geology*, p52)

Bedding-plane Slip Movement along a bedding-plane: usually an accomodation structure during folding or faulting (*ibid*)

Black-band Ironstone Staffordshire pop group?

Boulder Bed Used by Indian geologists as an alternative to nails

Catastrophism Philosophy of earth sciences students with regard to assignments

Fractive Cleavage Affects incompetent layers lying in a series of beds of varying degrees of competency (*Penguin Dictionary of Geology*, p85!)

Country Rock Latest pop craze

Crush Belt Group of earth sciences students in confined location, eg fault, mine entrance, loos at coach stop (and some bars)

Deflation State of student on receipt of R4

Depression Follows from above

OUGS Devil's Dictionary

Arkose Waterproof leg-gear - usually needed on field trips

Boulder Bed One used by the less inhibited

Braggs Law A law describing the way in which a ray of hope is reflected (or, more strictly, exaggerated) in conversations between two or more members of the same gender. The equation is:

2 L, I sin B (pronounced 'better')

I'm sure you don't need the translation!

Clints Ridges in bare limestone rock surfaces - usually dipping Eastwood

Unit Term of derision

Outlier Younger OUGS member sleeping in the open completely surrounded by older OUGS members (in tents)

Marine Band Term especially applied to those performing at an aqueous interface - usually includes 'percussion figures'

Marine Erosion Term used to describe destruction of 'marine band'. Erosion is carried out by the sea itself, acting as a hammer on the members of the band and, therefore, shattering them - look especially for 'percussion marks' - but the process is reinforced when on-lookers are armed with rock fragments (apologies to the *Penguin Dictionary of Geology*, p282!)

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Conference 80

Dr. John Wadsworth of Manchester University started the 1980 proceedings after the reception and buffet on Friday evening with a talk on 'The Evolution of Large Basaltic Shield Volcanoes'. As well as the more obvious two dimensional features of such volcanoes, the dimensions of depth and time must be added if we want to study *The Compleat Volcano*. By looking at Etna, Hawaii, Reunion and Rhum it is possible to see the impact of these four dimensions and to compare volcanoes from the four major ocean basins, the Mediterranean, Pacific, Indian and Atlantic, at the same time.

On Etna, erupting lavas can be studied in detail in an attempt to deduce what is happening inside the volcano. The processes by which the lava is formed can be recorded and, if the resultant lava is compared with the rock types associated with old volcanoes, a general theory of volcano formation can be put forward. The temperature of the erupted lava can be measured and the rate of cooling deduced to further strengthen any theories.

The Hawaiian volcanoes provide evidence on a slightly longer timescale because they store magma. The stored lava affects the shape, size and output of the volcano over periods that range from days to years. Chemical and petrological studies show the compositional changes of the magma over time and distance, and from these it is possible to recognise 'batches' of magma, and even when those batches get mixed together. A series of craters on the East Rift Zone of Kilauea provide an interesting place to study lavas that pool into fairly deep collapse craters that are up to 1km across. Here they can remain molten for many years after their eruption, allowing a long term study of lava cooling down that can be extrapolated to show how similar cooling within the magma chamber would progress. Kilauea Iki Lava Lake has been tapped as it cooled since its filling in 1959 to provide such information. It has shown the thickening of the crust, which was 44 feet deep after only three years, and allowed geologists to measure the changes in temperature and composition as the various fractions, such as olivine crystals, solidify out of the magma.

Active volcanoes can also be used to provide information on a slightly longer timescale by considering the patterns and effects of past eruptions. Etna, which has 1000 years of historical records associated with it, is particularly useful in this way. Beyond 1000 years it is very difficult to obtain information by accurate radiometric dating over periods less than 50 000 years, so hindering accurate recording of past events.

Hawaii also provides evidence over a slightly longer period in the form of the island chain associated with the current volcanoes. Each island represents a different stage in the evolution of the 'type' volcano. The main stages can be summarised into: a shield stage, when large piles of basalts are built up from the sea floor to sea level, and then subaerially (where substantial calderas are usually formed), this process normally taking only a few hundred thousand years; a

declining stage where the rocks start to range from basalts to trachytes and are normally erupted from small cinder cones on the sides of the volcanoes, often causing the caldera to become filled in; and a rejuvenation stage where small basaltic volcanoes appear across the eroded large volcano. These stages are represented by Mauna Loa (on Hawaii), Mauna Kea (also on Hawaii) and Oahu island respectively.

Reunion lies in the Indian Ocean between Madagascar and the Mid-Indian Ocean Ridge to the south of the Mascarene Basin and Plateau, and is near two other volcanoes on Rodrigues and Mauritius. It is not, however, part of a chain, as a cursory glance at a map might suggest. When looked at in detail the three volcanoes can be seen to be associated with different tectonic features.

There are two adjacent volcanoes on Reunion, one active, the other dissected enough to show its past history. The diameter of the volcanic edifice forming Reunion is 200km at its base, and it rises through 4000m of water before reaching sea level, where it forms an island 50km by 70km, and then rises a further 3000m into the atmosphere. The active volcano at the southeast of the island is very similar to the active Hawaiian volcanoes. 20km northwestward is the old volcano, now deeply dissected, which is of the same type as the active volcano, but 1-2 million years older. On the dissected flanks of the active volcano rocks 200-300 thousand years old can be seen, and the volcano is probably about half a million years old. The old volcano contains rocks ranging from 2 million years old, exposed in deep gorges in the central part of the volcano, to flows only a few tens of thousands of years old near the present summit. The oldest exposed rocks consist of thin, pillowy lavas rich in olivine and brecciated material, suggesting a shallow submarine environment. These deposits are now found up to 1km above sea level, and they are overlain by more normal subaerial basalts of the shield stage. About 400 000 years ago there appears to have been a break in the volcanic eruptions for about 50 000 years, after which the old volcano entered the declining stage, when light coloured, thick lavas were erupted, ranging in composition from basalts to trachytes.

In the eroded central core of the old volcano many intrusions can be seen, each of which can be associated, on detailed analysis, with one of the stratigraphic layers of the volcano. They are accompanied by the reconisable effects of thermal metamorphism in the form of mineral deposits in the vesicles. The core also shows some layered gabbro that might have originated in part of the magma chamber.

The final volcano covered by Dr. Wadsworth, Rhum, allows us to see right into the centre of the magma chamber. The Skye, Rhum, Mull Hebridian volcanic complexes on the west coast of Scotland have a very similar shape and spacing to the currently active volcanoes on Hawaii. Rhum contains strongly faulted and uplifted coarse-grained subvolcanic rocks separated from Precambrian sediments by a series of ring faults. It consists mostly of layered gabbros. The layering occurs on two scales, one of tens of metres, the other analogous to bedding in sedimentary rocks. Rhum has a very large positive gravity anomaly, suggesting

that the subvolcanic igneous rocks might extend to depths of up to 10km. The layered gabbros show evidence of lateral movement of the crystal mush, including some slump features where they became unstable. Some of these features resemble small scale overturned folds. The crystal layers also include 'scree' type deposits within the magma chamber, the scree consisting of layered gabbro fragments which have sunk through the chamber, sometimes distorting the pre-existing crystal layers on impact. Some of the structures in the central zone are extremely complex, especially where feeder pipes may have entered the chamber. Rhum also shows evidence of various eruptional phases, each associated with a different group of magmas, so relinking us with the other volcanoes covered by this talk.

Discussion

Q Do you subscribe to the concept that all the Hawaiian volcanoes come from the same mantle plume?

A Not entirely. The so-called plume must be an area capable of feeding 5 or 6 volcanoes, over which the plate travels. The rejuvenated volcanoes have an entirely different magma source from the primary ones, which the hot spot concept does not explain.

The Saturday morning session was started by Geoff Brown, the OU's granite specialist, talking on 'Granites in the United Kingdom Crust'. There are, strictly speaking, very few true granites in Britain, but granite/tonalite/diorite features are to be found throughout the islands. They can be divided into three main groups; Caledonian granites in the north of Scotland, Tertiary granites along the west coast of Scotland and Hercynian granites in Devon and Cornwall (each of which is also represented elsewhere in Britain).

There are two types of basement rock associated with the British Isles, those associated with the old American plate and those associated with the old European plate. Most of the Caledonian granites are related to the closure of the suture line between the two plates. Sesmic profiles show that the rocks at depth on either side of the Southern Uplands have differing compositions. Under the northern, American plate rocks 2000 million years old have been proved in the Lewisian gneiss, and rocks of a similar composition formed the source of magmas intruded in the north of Scotland during early Caledonian times. The rocks under the southern, European plate are of late Precambrian age, the oldest rocks found to date being the Malvern complex and granites like them retrieved from the Coal Board's Melton Mowbray borehole.

The northern Caledonian granites can be divided into two periods, with one group of pre-Silurian age and the other of Silurian/Devonian age. The Cairngorm granites have been studied by a gravity survey as well as on the ground and show a very strong negative gravity anomaly, indicating that the granite carries on down to more than 12km below the surface and that it has a broadly domed shape. Gravity surveys of the whole of Scotland show that there is little or no

anomaly in the older, forceful granites but large anomalies for the later, discordant granites. Normally the older granites are smaller in size and blend into the surrounding rocks better, and the younger rocks show higher U but lower $^{87}Sr/^{86}Sr$ initial ratios. As the older granites are similar in composition to their host rocks it is almost certain that they are formed from melted crust, whereas the younger granite intrusions are melts that have come almost straight up from the mantle in a destructive margin area.

The Lake District granites follow the same older/newer pattern. The Shap, Skiddaw and Eskdale granites are newer ones, whereas the Threlkeld St John's granite and Ennerdale granophyre are older ones. The dome-shaped Shap granite typically shows a uranium and gravity anomaly. The Skiddaw granite shows mica associated with quite strong mineralisation, particularly of wolfram, which is mined for the tungsten. The older Ennerdale granophyre, by contrast, is much finer-grained and is of similar composition to the country rocks surrounding it, whereas the Threlkeld granite shows evidence of multi-stage crystallisation, with large crystals of quartz and feldspar in a fine-grained groundmass. When these rocks were emplaced the Lake District was probably an island arc on the European plate, which was colliding with the American plate. This was around 400-500 million years ago.

The Hercynian Cornish granites, which extend as far as Spain and Ireland, are batholiths intruded mainly into Devonian rocks. They contain two-mica granites, which have both the boitite and muscovite forms of mica within their quartz/feldspar matrix. They are extensively mineralised, and in places the quartz has been altered to kaolinite. Tin, tungsten and uranium are found in the mineral veins. Geochemical analysis shows that the Cornish granites have the same composition as the Cairngorm granites, which is thought to be a typical I-type granite from an igneous source under a subduction zone. This is rather surprising in that the Cornish granites are traditionally associated with the non-subduction collision zone, typical of the Alpine-Himalayan chain generally, and such zones would be expected to show S-type granites from a sedimentary source. It could be that the hydrothermal action has caused S-type granites to be altered to I-type granites, or it may be that our understanding of the differences between I and S-type granites isn't as clear as we like to believe.

The Tertiary granites of the Scottish islands (and on Lundy Island in the Bristol Channel) are not associated with collision zones but come from an extension zone, and therefore have plenty of associated ring dykes. They also show the typical alkaline granites of zones of extension. Ailsa Craig, south of Arran, has granites with unusual columnar jointing which, combined with their fine-grained nature (they contain alkaline amphiboles), makes them ideal for curling stones. On Skye the granites intrude 60 million year old lavas, being themselves only some 53 million years old. At the Skye Marble Quarry there is a contact zone between the unaltered Beinn a Dubhaich granite and a Cambrian limestone deposit, giving rise to a olivine-rich skarn, whilst the slightly older Creag Strollamus epigranite has been altered by hydrothermal activity.

Discussion

Q How do the uranium plots produced in the granite surveys relate to the background radiation levels?

A The maps are built up from readings taken on stream sediments and waters, so where you see peaks on the plots the background radiation is likely to be very high. In places such as Aberdeen, where the houses are built of Cairngorm group granites, the background radiation is many times the level of that leaked from Winscale some time back.

Q Is there any age determination for the basement rock that formed St. George's Land?

A It is not any older than 600-700 million years. The only age determination I remember is the Charnwood one of 450 million years old, though the Malverns are probably a bit older, say 600 million years. There is no evidence of lead isotopes indicating older rocks in the southern province.

After coffee Professor E H (Howel) Francis of Leeds University took on the subject of the 'Mechanisms of Igneous Intrusion', looking principally at basic sill formation. Most large sills are found in the cratonic rather than the oregenic areas, and they are often, but not necessarily, associated with basaltic volcanoes.

Area found in	Cratonic	Oregenic
Type of rock	Basic	Acid and intermediate
Source	Upper mantle	Basal continental crust
Temperature at intrusion level	1100-1200°C	700-950°C
Viscosity on intrusion	10^3-10^4 poise	10^5-10^9 poise
Density	2.9-3.0	2.7±0.2
Ascent rate	5-50km/yr	20×10^{-6} km/yr
Ascent method	Dykes along fractures	Diapirism
Final form	Displacive sills	Plutons and batholiths, partly replacive

Table 1

Table 1 shows the main physical differences between the basic cratonic and the acidic oregenic intrusions. The granitic magmas are thought to rise by Stokesian principles, where droplets are formed which are lighter than the surrounding material and rise because of their natural bouyancy, coalescing as they rise to form batholiths up to 70km in diameter. Ramburg has centrifuged materials of varying densities and achieved results very similar to known batholiths.

In contrast, basaltic magmas are presumed to come from the mantle along

fractures. Ramburg's experiments have shown how, when extra material is intruded into his models to cause updoming of the crust, a series of ring dykes and radial fractures can be formed. These experiments have shown how important stress and strain are to sill and dyke emplacement.

All the major sills in the world have been emplaced in sedimentary basins having up to 6km of relatively undeformed sediment. In all cases these basins sit on granitic or metamorphic basement. The sills are nearly all emplaced at depths of between 1 and 2.5km below the sedimentary surface. Depths of over 50km are required for lithostatic pressure to dissociate the liquid part of the magma from the remainder of the mantle so that it can begin to rise to the surface. The pressure of formation is sufficient to raise the magma column to near the surface, but around the point where the density of the overburden becomes less than that of the magma column the upward pressure dies out, and the magma cannot rise any further. Further movement can then only be lateral unless other factors come into play to allow the magmas to be intruded on the surface to form volcanoes. These factors include having fairly consolidated sediments, the hardening of the conduit walls by marginal heating whilst it rises, and the release of water from the sediments which the magma can heat up to form gas which is capable of explosively ejecting the magma.

Mudstones are thought to act as a barrier to magma penetration, sills often being found immediately below them. Sometimes, as is seen in the Eureka Sill in Tasmania, the sills form flattened cone sheets. The Eureka Sill is 50km long and 9km wide, with a depth of up to 450m. The Whin Sill also has a basic saucer shape reminiscent of these cones, but though it covers a much larger area than the Eureka Sill its maximum thickness is 50m. The Whin Sill also has east-west dykes associated with it, which may have acted as feeders and which extend outside the area covered by the sill.

The sills in the Midland Valley of Scotland can be seen to step from one bed to another, spreading along a bed until a point of weakness allows it to rise to the next bed. 'Horns' are also found here, where oval fingers of a sill have separated out. Various theories have been put forward to explain this stepping and fingering, but none is entirely satisfactory. One proposes that the sill is preceded by a gas 'bubble' which breaks up the rock in front of the sill. Another suggests that the steps are formed between fingers and are therefore at right angles to the direction the sill is spreading in. Bradley, however, proposes yet another concept that puts the steps into the directional flow of the sill, using tension spaces similar to the tension gashes found over anticlines and voids in front of the magma.

Another problem is presented by the sheer size of sills, which greatly exceed anything extruded by volcanoes. As the sills are so thin, and therefore are cooled at their surfaces so quickly, how are they able to spread so far before becoming 'seized up' by cooling? Possibly it is because the magmas lack phenocrysts around which cooling can be concentrated and which can slow the initial flow. Temperatures well above the magma melting temperature would also allow longer flow

periods, and in places contact metamorphism effects up to 10m from the sill indicate that a great heat must have been associated with the emplacement of a sill. Another possible reason for the large spreads of sills may be that they are fed from multiple points or dykes, rather than being single source events, though this makes the cone shape problematical.

Discussion

Q Are we certain that the sill material is derived from the mantle rather than the crust it comes through?

A The minerals in the sills would require depths of around 60km for formation and fractionation. Their composition is similar to that found on ocean ridges, which again indicates a mantle origin.

Q Does it bother you that the gas blasting and tensional gashing propositions provide nice clean breaks without any suggestion of brecciation in the process?

A The ideas seem to have preceded observation, but maybe observation will show brecciation. Brecciation is shown when a sill tears across a bed, as can be seen near the Forth Road Bridge.

Q Is there any evidence of current sill emplacement?

A Perhaps 50% of magma is trapped in the crust rather than erupted at present. About 1km^3 of sills are intruded each year.

Q As granites have a lower density, if they form sills the hydrostatic pressure theory would suggest they should be formed at a higher level than the basaltic sills. Is there any evidence of this?

A George Walker argues that granite diapirs stop at a barrier that is again dictated by hydrostatic pressure, though the lateral spreading is more difficult as phenocrysts are present and the temperature is lower. Also many granites are less dense than the rocks they intrude.

The Saturday afternoon session was devoted to two of the currently most active volcanic areas, Iceland and Mount St. Helens. Karl Gronvold of the Nordic Volcanological Institute at Reykjavik started his talk by describing the general geology of Iceland. There are no fossils in Iceland as all the rocks are volcanic. There are three main units; the Tertiary flood basalts in the east, west and central northern areas, the sub-glacial and acquatic Pleistocene pillow lavas and, in the central zone, the currently active volcanic zone. These units are being mapped in detail by the use of the potassium-argon dating and magnetic reversal detection techniques.

The flat lying Tertiary flood basalt lava flows show dip structures towards the central volcanic zone due to the tectonic lifting of the lava as it ages. This is normally in the oppostite direction from the original lava flow direction, which goes away from the volcanic area. But in certain areas these dip structures are seen to change and George Walker, mapping one of these areas in the 1960's, showed that these changes were caused by an old volcano within the lava flow. A number

of these volcanoes have now been identified, with hieghts of up to 600m. They have a life of 1-2 million years each, before being reburied by the flood basalts. Each volcano has one or more dyke swarms associated with it. Similar features can be seen in the currently active zone, though here the dykes are represented by fracture zones. Gravity anomaly maps show that a series of volcanoes can be traced eastwards under the sea between Iceland and the Faroes, from where they can be linked to the Hebredian complex to show the extent and timing of the opening of the Atlantic.

Flood basalts only account for some 40% of the crust formed during the Tertiary, the other 60% being formed by dykes injected into the rift zone. Drilling to depths of 14km in the rift zone has shown that all the lavas were ejected above sea level, indicating that there must be continuing subsidence. A consequence of this is that all the rocks seen at the surface must have been ejected near the margins of the rift zone, whereas centrally ejected lavas will always get buried below the surface, at depths that can exceed 10km. As the centrally ejectd lavas descend they pass through a fairly steep thermal gradient which alters them from greenschists to amphiboles and granulites.

There is a whole spectrum of volcanic rock on Iceland, from basalts to rhyolites. Each volcano has its own spectrum of identifiable rocks associated with it, these differing from those found in other volcanoes in such things as sodium and potassium content, etc. Studies of the acid tephra ashes on one volcano have shown that the silica content decreases with time even in short-lived eruptions (from 72% to 56% in this case). Basalts also show variations, from quartz-tholeiites to olivine-tholeiites and alkaline-olivine basalts.

Since 1975 Karl has been studying the current rifting in Iceland. In 1938 the northern part of the fissure area was measured, and at this time an expansion was detected. In 1955 the Germans used electronic devices to remeasure the area. When they returned in 1971 they found the area had contracted! In 1975 they remeasured, and found a very slight expansion!! By 1975 this movement had increased perceptibly. The expansion rate in Iceland is not 1cm/yr, but 1m/century, with periods of consolidation in between.

One of the larger structures on Iceland, Krafla Volcano, became active again on 20th December 1975, having been dormant since 1875. There have since been two eruptions in 1977 and another in March 1980. There is a magma chamber about 3km under the caldera, but the caldera itself does not rise and fall as in some volcanoes, though some of the surounding ground does. It is a flat-shield volcano, and may have more than one magma chamber as the centre of inflation shifts around quite a bit. The magma chambers appear to have an inflow rate of $5m^3/s$, but only about 1% of this reaches the surface, the rest being injected as dykes into the rifts. The deflation of the magma chambers occurs quickly, whilst the build up is fairly slow. When deflation is taking place faults can widen by as much as 2m in less than a day, and the surrounding land may drop as much as 60cm to compensate. This is all accompanied by earthquakes which include vertical as well

as horizontal earth movements. The last rifting in this area occurred in 1724, when three major rifting episodes were recorded, followed by volcanic activity betwee 1727 and 1729. The lavas now being ejected show variations in composition both on the small scale within the flows and between the various events themselves, matching the findings in the Tertiary volcanoes.

Karl finished his talk by showing some dramatic shots of active rifting taken by himself and some of his colleagues. The first shots were taken from a plane flying over the Krafla volcano. Then he showed the effect of rifting on roads and other items such as the hot water supply pipes to geothermal power stations. Lakes and power stations make good level detectors to show the rate of magma chamber movements, especially if you put nails all around the lake to measure from! The final set of shots were taken by two of Karl's colleagues who were using snow scooters to get around on a measuring survey. Suddenly an eruption occurred near them, and they were able to take a dramatic series of photographs of the rift's progress, nearly being caught by the fast moving lava flow in the process. The lava was moving over the snow at a rate of 10m/s, not melting it first. As this is faster than the average athelete can achieve it was lucky they were using snow scooters to get around!

Discussion

Q Are the volcanoes currently erupting on Iceland of the same size as the ones found in the Tertiary strata?

A Yes, they are of the same order of magnitude.

Q Do the flood basalts come from the volcanoes?

A No, they come from fissures that can be formed anywhere in the active zone. The volcanoes include acid and intermediate rocks not found in fissure eruptions.

Q Do you get S waves passing through the molten layer on which Iceland rests?

A Yes. It is only a semi-molten layer and does not cut out all of the S waves.

Whilst it is difficult to find a more exciting area of volcanology than Iceland, our next speaker, Peter Francis of the OU, had managed to spend the previous few weeks studying an even more topical volcanic event, the eruption of Mount St. Helens in Washington, USA. Many distorted reports of the activity of this volcano have appeared recently in the press, and Dr. Francis took the opportunity to present a full summary of the events to the OUGS members attending the conference.

Mount St. Helens was very well studied in the States before the present series of events. Crandell and Mullineux of the US Geological Survey (USGS) produced a volcanic hazard map in 1975 based on the previous volcanic activity. Mount St. Helens has the longest record of activity of any volcano in the USA. The last documented eruption was in 1856, when a fairly small eruption of ash and steam was accompanied by a large bang. The hazard report showed where the previous mud and lava flows had gone, and where ash had fallen, and it pointed out the dangers of the volcano exploding again. In 1978 the authors predicted, in a paper

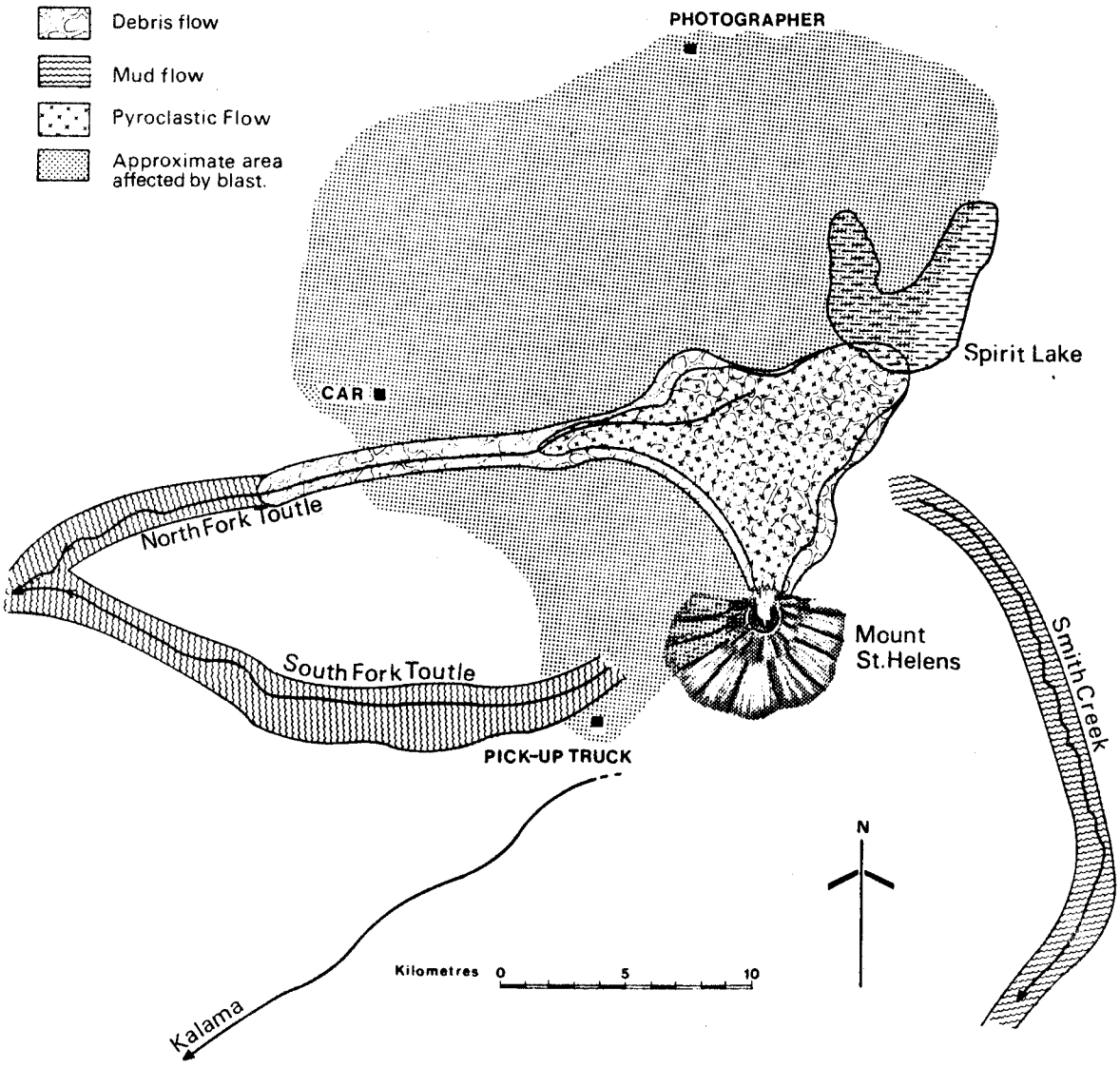
published in Science, that the volcano would erupt before the end of the century, but no one took any notice of them! So there was no reason for being unprepared, though, as it turned out, people were incredibly unprepared.

The first event to draw attention to the mountain occurred on March 20th, when a magnitude 4 earthquake centred on the volcano heralded the start of almost continuous siesmic activity. The first visible sign was an ash eruption on March 27th. Between March and April the ash eruptions continued, and the constant siesmic activity decreased in the manner typical of an harmonic tremor, which the USGS geologists attributed to the ascent of magma inside the volcano. This made them realise that a large eruption was a possibility. During late April and early May a bulge started to grow on the north flank of the volcano, and early in May it was growing at the rate of 1m per day. As a result of this the USGS had the area evacuated as far as they could, and established a Red Zone around the volcano into which people were not suppossed to go. But the evacuation was only partial as some people refused to move and others came into the area out of curiosity, a fact which led to most of the eventual death toll. The volcano looked very tranquil prior to the eruption. Indeed the USGS had issued a statement to the effect that the volcano was in a 'tranquil phase', as it was. They had done a very good job of monitoring the volcano, they had taken the right decisions about evacuating the Red Zone, and it was people ignoring these warnings who were caught by the eruption.

On May 17th and 18th Keith Ronnholm, a graduate geology student on a camping holiday near St. Helens, took a remarkable series of photographs of the volcano during its main eruptive period, including before and after photographs. These show the mountain on the night before the eruption and on the day of the eruption from a few seconds after the eruption at 8.32 to a shot taken at 12.28 from some distance away. The first shot of the morning showed the major debris flow landslide (see map) starting to move down the north flank of the volcano, with the main failure plane clearly visible. Accompanying this was a horizontal nuee cloud, which had already overtaken the landslide only seconds after the start of the eruption, and a burst of material being explosively ejected from behind the landslide, together with a vertically directed ash cloud. The debris flow represented one cubic kilometer of detached volcano spreading down into the north fork of the Toutle River.

10 seconds later the second photograph showed the nuee cloud a long way down the mountain, with blocks and bombs being explosively ejected well in advance of the main cloud from deep within the mountain. The ash cloud was starting to climb at almost 1000m per minute. Within the next few seconds the nuee had crossed the valley floor and started up the slope on the other side. Wisps of pure white vapour cloud started to appear among the dust due to the moisture ejected by the explosion.

Later shots showed how the nuee spread out above ground level so that the nuee front preceded the material that caused the damage on the surface. After some 8 or



9 shots, including one of the thunderhead-like top of the ash cloud, Kieth was forced to hurriedly vacate his campsite to avoid being engulfed by the nuee. Within minutes of the eruption the ash cloud had reached a height of 20km, before spreading out in the stratosphere.

The order of deposition is shown in Figure 2. The first deposit was the cold debris flow (for area covered see map, Figure 1). This was the product of the top 250m and the whole of the northern flank of the volcano, which left a crater 1km by 1.5km about 750m deep on the summit. This mass swept 300m up the opposite slope of the valley before it spread 20km westwards down the north fork of the Toutle. The distance travelled up the sides of the valley indicates that it was

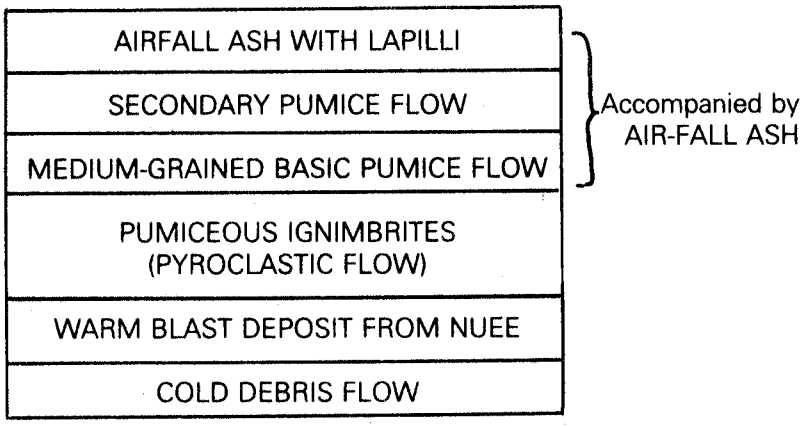


Fig 2

travelling at some 75m/s when it reached the bottom of the valley. Immediately below the volcano the debris flow is some 130m thick, but as it came to a stop some 20km downstream it was only 2-3m thick. The valley sides show scouring marks up to ½m deep from the passage of the debris flow. These are very similar to those caused by glaciers. The original ground surface was planed off to a depth of about one metre on the valley floor.

The debris flow was principally a dry flow consisting of rock, boulders, glacier ice, pulverised rock and small fragments. The mobilising medium was air. It is characterised by its high ratio of thickness to width, being highly channelised along the Toutle valley. It has a hummocky appearance where it pokes through the overlying deposits, and includes large blocks of oxidised red scoria, from near the vent area of the volcano, and glacier ice, which is now melting away and leaving kettle holes in the deposits. Further down the valley the flow caused large, highly destructive, mudflows for 60km down the Toutle, Cowlitz and Columbia Rivers. It also backed up the south fork of the Toutle. The Columbia River had to be redredged to recover its navagability after the inflow of mud, which was up to 6m deep in places. Most of the damage was caused by the felled logs picked up by this mudflow. In the other direction Smith Creek (see map) was also affected by mudflows.

Blast effects cover an even larger area (see map), which had a fairly sharply defined margin about 100m wide in which the trees changed from being totally destroyed by the blast to being totally unaffected. These blast effects preceded the debris flow, though they only had a speed of 30-50m/s, and in places the debris can be seen to be overlying trees felled by the blast.

Most of the nuee deposits occured outside the area covered by the debris flow, on the slopes opposite the volcano. Many of the deposits on the side of the valley later slipped back to the valley floor to cover the debris flow. Within 10-12 days these still hot ashes had been deeply dissected by river erosion. The nuee deposit contains material from the older part of the volcanic cone, with no young magmatic products. It is very badly sorted, ranging from large boulders to the finest of fine dusts, with lots of uncarbonised woody material enclosed in it. Up to 8km from the volcano deposits 0.5m thick accompanied the nuee where it killed a photographer in a parked car (see map). The car did not, however, show any affects of sand blasting, though its windows were shattered. The occuppant died from seared lungs caused by the hot gases, though the temperature did not affect any of the plastics or flammable material (paper or petrol) in the car.

The nuee also affected the southwest slope, where the occupants of a pickup truck were caught by a blast that only affected the floor of the valley they were in: about 200m up the slope the trees were unaffected. There was very little ash deposit here, but the fragments were enough to affect the plastics in the truck, and the air blast was sufficiently powerful to bury a 15cm splinter into the seat. The truck was badly battered but not sand blasted, indicating that the damage was principally caused by large rocks and heavy debris such as logs, which shows a fairly high wind velocity, though not high enough to turn the truck over.

The eruption didn't stop with the debris flow and nuee, but continued for 8 to 9 hours on May 18th. After the initial violent episode a vertical ash column developed, which partially collapsed later in the day to produce a pumiceous pyroclastic flow. Radar studies of the ash cloud showed that it had four major surges, each of which was accompanied by a distinguishable deposit. The map shows the restricted area of the deposited pyroclastic flows, which extended into Spirit Lake. They have a very smooth surface, and flowed around the hummocks of the debris flow to a depth of up to 40m. In S23- terms this ash deposit is an ignimbrite, but it does not have the welded particles shown in the units. It contains larger lumps of older material within juvenile magmatic material from the volcano. Even 10 days after the eruption the temperature 2m inside the flow was 330°C, so at eruption the temperature was probably around 6-700°C. Where these flows had extended over the wet ground surrounding Spirit Lake the reaction of these hot deposits with the water caused the violent production of secondary pumice flows from a large number of explosively produced secondary craters. These secondary eruptions produce a pale ash which can be thrown as high as 1000m into the air.

Later in the afternoon medium-grained pumice flows were deposited on top of the ignimbrites from the ash cloud. These contain a darker coloured basic pumice in contrast to the earlier slightly acidic pumice flows. Secondary pumice flows are associated with these flows as well, sometimes showing reverse grading which might be caused by their being water rather than gas mobilised. The ash fall deposits on top of the pumice spread over a very large area of the USA, where

deposits were deep enough to affect airports, roads and crops. It reached as far south as Texas, and as far east as New York. The ash deposited is characterised by its sticky and muddy nature, as opposed to the hot dry nature of the ash from the nuee.

Discussion

Q Were there any after effects of the eruption?

A There have been two small ash eruptions since May 18th, one on May 25th and the other on June 12th. Another small dome has grown to 80m high in the last two weeks. A similar volcano in Guatemala has had a dome which has periodically produced nuees for the last 60 years!

Q Are there other volcanoes in the area, Mount Rainier for instance, likely to be affected by this eruption?

A (from Ray Macdonald) There is a tendency for these Cascades volcanoes to go off in sequence.

Q How accurate was Crandell and Mullineux's prediction of the hazard?

A Very good. Their map was almost identical to the map of what actually happened.

The speaker on Saturday evening was Dr. John Rae of Oxford Polytechnic, who chose as his subject 'Mineralisation and Igneous Processes'. Dr. Rae started his talk by explaining the importance of igneous processes generally, taking as his starting point events throughout the solar system, from the eruptions on Surtsey to the 100km high eruption on Io, one of the moons of Jupiter. These latter differ from those we are used to because they are driven by sulphur dioxide and eject sulphur fragments. Io has been completely resculptured by these eruptions, eight of which were detected on the short Voyager flybys, making Io the most active planetary body in the solar system.

On Mars volcanoes such as Mons Olympus, the largest volcano in the solar system, have also played an important part in shaping the planet. Three times as large as Mauna Loa, the largest terrestrial volcano, it reaches to a height of 20km from its base. The Moon shows the results of volcanic activity, particularly in the infilled Mare basins and the unusual sinuouss rill features. Venus is not so easy to see, but radar mapping suggests the possibility of volcanic and tectonic processes. Mercury also has infilled basins similar to those on the Moon.

On the Earth we can regard the crust as being an igneous feature containing other rocks secondarily formed from igneous source rocks. Igneous processes offer evidence of major structural changes taking place in the upper mantle and play an important part in the formation and recycling of the atmosphere and hydrosphere. Volcanic activity has also contributed to the origin of life on Earth through the provision of prerequisites such as water, and possibly by providing favourable local conditions - gas mixtures, electrical discharges, high energy sources, etc.

But perhaps the most directly important part played by igneous activity in our life is through volcanic mineralisation. Pumice erupted from volcanoes is used as a lightweight aggregate, granites make beautiful building stones, and ignimbrites and obsidian have been used as tools by Stone Age tribes. Volcanoes, however, also act as vast, uncontrollable mineral factories within which specific elements can be concentrated hundreds and even thousands of times over their normal crustal abundances, to form mineral deposits.

These concentrations are acheived in a number of ways, some of which act on igneous rocks themselves, others acting on water circulating through the rock. Sedimentation offers a way of concentrating minerals by simply sorting the weathered minerals by density. In lateritic conditions nickel from ultrabasic volcanic rocks is often concentrated because it is less likely to go into solution than other minerals. Gold placer deposits which settle preferentially from suspended material because of the high density of gold particles are probably the best known example of products weathered from igneous rocks. Uranium is an example of a soluble volcanic element that can later be redeposited under suitable (reducing) sedimentary conditions.

The igneous processes themselves have a number of advantages when it comes to concentrating minerals. They are highly energetic and capable of transporting material. Also they tend to be multi-phase processes, involving solids, liquids and gases, so offering different ways in which elemental concentration can occur. Sublimation from a vapour to a solid allows the concentration of elements such as sulphur. Liquid/liquid immiscibility in igneous systems is also responsible for important mineral deposits such as the Sudbury, Ontario, nickel deposits and the Rustenburg platinum deposits. Liquid/solid phase reactions (crystallisation and sorting) produce magmatic segregation deposits like the Bushveld chromites. The old idea of the settling out of crystal within a convection cell in the magma chamber being the main source of such liquid/solid sorting is now being replaced by a concept in which differential nucleation within a series of discrete liquid layers is responsible for the concentrations of minerals found. Even the liquid left after crystallisation is enriched in certain elements, and pegmatites such as those found in the Donegal granites contain possibly economic concentrations of uranium.

Hydrothermal mineralisation involves the interaction of water with rocks to form solutions that are later deposited in veins. Such hydrothermal solutions have temperatures as high as 500°C, and are capable of leaching elements from the rocks through which they pass. There are five fundamental prerequisites for the formation of a hydrothermal mineral deposit: there must be a source, water to provide transport, energy to drive the system, transportation routes such as are provided by faults and permeable strata, and a localised, but continuous, mechanism for inducing precipitation of the mineral. All of these prerequisites can be provided by igneous processes, but not all of them are provided by igneous sources at every occurrence. Water is only rarely supplied from magmatic sources, and precipitation may be provided by the atmosphere rather than igneous activity.

For instance, in the Troodos mountains of Cyprus the copper sulphides in the ophiolite complex result from the reaction of seawater on the pillow lavas of the complex, driven by igneous heat through routes around the pillow lavas. Deposition results from chilling at the rock/seawater interface. Porphory copper deposits in such places as Chile also derive from an igneous source, using igneous energy and, in this case, magmatic water for at least the early stages of mineralisation. Silver in mines such as those in Bolivia has been formed by epithermal precious metal mineralisation immediately below volcanic edifices. Here the igneous processes provide the source, the energy and the channels (sometimes through caldera collapse) in which deposits can be made.

Each of these types of deposits can be tied into a typical area of plate tectonic activity. For instance, the Cyprus-type copper sulphide deposits are associated with constructive plate margins, whereas porphory coppers and epithermal precious metal deposits are found at destructive margins.

Looking at the British mineral deposits it can be seen that many are related to igneous processes. Nickel resulting from magmatic segregation within gabbros near Aberdeen, tungsten from hydrothermal vein deposits from granites in Carrock Fell, porphory molybdenum and copper within Caledonian acid and intermediate intrusives, tin in veins in the Hercynian Cornish granites and, within extrusive volcanics, at places such as Parys Mountain on Anglesey, copper mineralisation of the Kuroko type provide a few examples of important British minerals.

Mineral deposits are not, however, restricted to just one planet in the solar system. Io could provide a good source for sulphur, perhaps becuase sulphur is not tied up in the core as it is on Earth, due to the very strong tidal force exerted by Jupiter. Mercury's high density indicates that it might be a good source for metals, possibly in the form of magmatic segragation minerals such as chromium and nickel. As Mercury has no plate tectonics there will be no mineralisation associated with subduction zones, etc. The Moon, dead for the last 3 billion years, may well also contain segregated chromite and, as there is a small or absent core, some siderophile metal deposits. Venus is a bit of a mystery as it is always shrouded in clouds, but radar studies suggest a possibility of plate tectonic types of mineralisation. Mars is the great imponderable as we are unsure when the internal activity stopped. We do know there is no obvious signs of plate tectonics and that outgassing has been slower than from the Earth so that hydrothermal, plate margin deposits such as porphory coppers are unlikely.

The importance of the igneous contribution to mineralisation should not be underestimated. Igneous processes are directly responsible for most of the world's deposits of chromium, nickel and the platinum group metals, and through their contribution to hydrothermal processes for much of the workable copper, tungsten, tin, uranium, gold, silver, lead, zinc, molybdenum, mercury and antimony.

Q What is the difference between the carbon content of Venus and Earth?

A When you take the CO_2 in the Venusian atmosphere into account there is little overall difference between the percentage of carbon on the two planets. The main difference is that on Earth much of it is tied up in plants and carbonate rocks.

Q Doesn't Venus have a highly corrosive atmosphere?

A It does at high altitudes, but not on the surface. One of the surprising discoveries from the Russian landers is the extremely low surface wind velocity, and hence the lack of weathering shown by the rocks.

The first session on Sunday morning, which followed all too soon on the highly successful disco of Saturday night, allowed us to gain an impression of some of the research work currently being undertaken by the graduates at Walton Hall. Three students, Greg Reeves-Smith, Sally Barritt and Dave Rothery, gave short talks on their current projects. Greg has been studying the amphibolite facies of South India, where he looked at the orthogneiss and greenstones in the low-strain area in the Archean gneiss near Hassan, and the associated higher-strain areas, where paragneiss, schists and amphibolites are seen, near Bangalore and Kudaremukha.

Near Hassan the orthogneiss is cut by glaucophane veins infilling the shears, and ptygmatically folded pegmatities are very evident. There are five different igneous phases in the area, ranging from acidic to basic, some of which have sulphur mineralisation associated with them. Phyllites can be found within the gneiss, leading to boudinages. Garnets in the schist provide good strain indicators, and Greg hopes to do strain measurements on some of the garnets he has collected. Using isochrons it is possible to show the rocks to be 3.4 billion years old, making them among the oldest in the world.

In the teak forests of the Kudaremukha area of the Western Gats chlorite schists and gneiss can be found. An iron mine works the banded iron formation within the gneiss, where magnetite is banded by quartzite. The terrain and weather is such, however, that geological work in these forested mountains is extremely difficult.

Sally Barritt has been looking at the British granites to try to determine their geothermal energy potential. If a granite is to be used to provide geothermal energy it must have an enhanced geothermal gradient near the surface. As well as the heat derived from the mantle itself it is necessary to work out the contribution from the radioactive elements within the rocks. The most suitable rocks are, therefore, likely to be those with high proportions of radioactive elements, such as are found in the late Caledonian granites of the Cairngorms, as Geoff Brown explained. Sally has been working on this complex and the granites around Lake Etive to the west.

The Etive complex is surrounded by Dalradian schists, and intrudes the Glen Coe complex. It is a ring complex formed by subsidence and stopping. It is a multistage intrusion, which started with a diorite, followed in turn by the

Cruachan granite. This varies in composition from tonalite to adamellite, increasing in acidity from south to north and from the bottom to the top of the intrusion. This was followed by the Meall Odhar aplogranite, which forms a cap-rock to the Cruachan granite, probably just being the last, highly acidic, stage of that intrusion. The Starav granite in the centre of the complex was intruded at a later stage. This is a true granite, with a porphyritic outer rim grading into a fine-grained centre, with acidity again increasing upwards and inwards.

At the northern end of the Cruachan granites the adamellite has a very high uranium content, whereas the Meall Odhar aplogranite has a very low uranium component. The distribution appears to be magmatically controlled, with the more acidic melts normally having larger radioactive components. Most of the uranium appears to be associated with inclusions in biotite and other minerals within the granites. In the adamellite the uranium is nearly all in sphene, which makes up 2.5% of the granite, whereas in the associated tonalite it is mostly held in apatite, having very little sphene. The areas of highest geothermal potential are, therefore, likely to be in the adamellite, but it is doubtful if this will extend far enough downwards to make this a viable economic source. The Starav granite is more likely to extend deep enough to be economically viable, even though it has a lower radioactive content, but drilling will be needed to prove this.

Dave Rothery has been mapping the Oman ophiolite with the aid of the Landsat satellite. Ophiolites are formed at spreading ridges and then thrust onto a continental plate. They start as gabbros, dolerites, pillow lavas, harzburgites (olivine orthopyroxene, which is a depleted mantle rock), etc, being deformed and slightly metamorphosed during the thrusting. In the Oman the ophiolite was emplaced in the Upper Cretaceous, being involved in the Alpine-Himalayan orogeny whilst Africa, Arabia and India collided with the Eurasian plate. The ophiolite overlies the Precambrian basement rocks of the Arabian plate and the Jurassic and Cretaceous carbonates that covered most of them, and in turn it is covered in places by Tertiary limestones.

As there is little vegetation or soil cover in the Oman mountains the rock types are well exposed, and it is possible to map a complete sequence from pillow lavas through dykes and gabbros down into the depleted mantle rocks (harzburgites) from which they are derived. Much of the gabbro is cumulate in texture and has probably formed by crystal settling in a magma chamber. It can show, for instance, alternate olivine-rich and olivine-poor layers. The harzburgites show tectonic foliation, presumably caused by shearing of the upper mantle within the base of the newly formed lithosphere on a spreading ridge.

As such a large area is involved Dave is attempting to use the images from the Multispectral Scanner System on the Landsat satellite to map the area. The satellite is 930km above the Earth, and records the area over which it is passing strip by strip in four different colour bands, one in the green area of the visible spectrum, one in the red area and two in shortwave infra-red. These are transmitted in digital form to computers, which can be used to produce images on various scales, combining images produced in different wavebands. The most useful

images have been found to be produced by false colour pictures combining all four bands, from which most of the rock types can be identified.

After coffee, Ray Macdonald of Lancaster University took us through the 'Geochemical Evolution of Large Silicic Volcanoes' in that period of our lives normally reserved for preachers and ministers! Ray took as his subject the relationships between silicic volcanoes and high level granite batholiths, looking particularly at those volcanoes specifically associated with large caldera collapses. You cannot trace the geology of just one silicic volcano, as you can never get to the pluton whilst it is active, so it is necessary to infer the processes involved from studies of many volcanoes. For the last 200 million years the western United States has had virtually continuous silicic vulcanism, now indicated by the Yellowstone Park geyser field. The largest series of explosive caldera collapses ever detected occurred during the Tertiary in the state of Colarado, and by combining the details from these eruptions with evidence from older volcanoes in the series it is possible to fit together a complete picture of the relationships between batholiths and silicic volcanoes.

The migmatitites in the Lewisian of northern Scotland can be seen to contain recystallised areas that are granitic in composition and form, and in places the folds of the migmatites can be seen as traces within rock that was obviously well on its way to becoming a granite. Such areas combine to form a batholith, which may also be augmented by crystal fractionation of more basic magmas. In places rock broken off the country rocks surrounding the original pluton also become assimilated into the batholith.

Near Santa Fe in New Mexico the 1.1 million year old Bandolier Tuffs from the immense Vallee Grande caldera collapse can be seen overlaying the Permian Red Beds. These beds, which were erupted in a matter of hours, have a volume of 200km^3 and are derived from explosively ejected granitic batholiths. They show chemical variation within the beds themselves, with 77% silica at the beginning of the eruptions and only 71% at its completion. This is the reverse of what would have been found in the magma chamber, showing that the chamber has been emptied from the top in a series of eruptions rather than all at once. These findings fit in with the thermal gravitation diffusion theory, which proposes a method by which rocks in batholiths can vary in composition with depth.

In the Coastal Range of California, Pleistocene granitic rhyolite domes can be seen, often overlain by basalts. The rhyolites seem to be increasing in volume as they get younger, and they are still being produced from an active magma chamber under the range, in which diffusion is probably still taking place at present. This area, therefore, has the potential of producing a large caldera collapse of the type that fromed the Valle Grande.

Ray also produced a series of satellite photographs of the Mount St. Helens volcano, which gave a very good idea of how the ash cloud spread across western America. When it is realised that this was a relatively small explosion, the widespread effects of the larger eruptions can be better appreciated. Some of these

explosions (such as the one that produced the Bishops Tuff) left recognisable *bands* of ash over most of the USA. The effect of such an explosion on the American grain crop would be disasterous, with more people starving to death because of the eruption than would be directly killed by it.

There is, however, a good side to large silicic volcanoes. They have a large geothermal potential, and the Americans are testing the Coastal Range batholith to see if this potential can be tapped economically. The energy in the Yellowstone Park batholith is about 100 times the annual world energy requirement, so it could potentially provide large amounts of energy, only a small proportion of which is currently being tapped.

Discussion

Q Will the use of the geothermal energy potential reduce the chances of an eruption?

A Negligibly, because heat couldn't be extracted with the present technology faster than it is being produced.

For the final talk after lunch on Sunday, Dr. Mike Norrie of Leicester University took on the extremely complex task of explaining the interrelationships of 'Isotopes and Igneous Processes' in just one and a half hours. Mike started with stable isotopes such as oxygen and hydrogen, which occur in water both in the magma and in the sediments that surround many volcanoes. In hydrogen the mass of the normal (hydrogen) isotope and its heavier (deuterium) isotope differ by a factor of two, making them chemically very different. The mass difference also means that 'heavy' water (D_2O) is less likely to evaporate than H_2O.

With oxygen the difference between ^{16}O and ^{18}O, the two principal isotopes, is much less proportionally, so making them harder to separate. The isotope ratios of volcanic, and other, water is measured against Standard Mean Ocean Water (SMOW) and plotted on a SMOW diagram using the formulae:

$$\delta^{18}O = \left[\frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{standard}}{(^{18}O/^{16}O)_{standard}} \right] \times 1000$$

$$\text{and } \delta D = \left[\frac{(D/H)_{sample} - (D/H)_{standard}}{(D/H)_{standard}} \right] \times 1000$$

Mantle derived rocks typically show $\delta^{18}O$ values 5‰ above the SMOW values, whereas evaporated rainwater, especially towards the poles, can show values down to −55‰, and in this case they are associated with δD values of below −300‰. Granites and acid rocks sometimes even go as high as 10‰, but in Scotland and other areas negative values have been recorded, particularly around ring intrusions. In Skye the rocks around the ring dyke range from +5‰ to −5‰. The only substance that the intrusions came into contact with that would have a ratio around −5‰ would be water, and either a long interaction with seawater or a far shorter one with rainwater could account for this change. The reverse of this interaction can be seen to occur in water circulating around geyser fields, where

the rainwater falling has its $\delta^{18}O$ value increased as it circulates around the geyser system. Obviously this interaction is stronger where there are more faults and cracks through which the water can percolate.

It is not certain if, or how, water gets into the magma chamber, or its effects when it does get there, but it certainly alters the rocks after they have solidified and/or as they are being metamorphosed by the intrusion. Isotope ratios can be used to determine the temperature of formation, as the higher the temperature the lower the $\delta^{18}O$ ratio in a given mineral, and to work out the minimum amount of water interacting with the volcanic intrusion.

When you come to look at the reactions of the unstable isotopes of such elements as strontium (Sr) and rubidium (Rb) the beta decay of the various elements have varying half-lifes that can be used to date rocks if you know the initial concentrations. For instance, ^{87}Rb has a half-life of 5×10^{10} years (50 billion years). Using isochron plots showing the ratio of the current isotope ratio of the rock against that of a non-changing related isotope (often ^{86}Sr) it is possible to determine the age of an eruption (from the slope) and the initial isotope concentration (from the intercept).

Using meteorites it is possible to postulate an initial isotope ratio for $^{87}Sr/^{86}Sr$ in the Earth, and comparing this with the initial ratios of other, younger, rocks the Sr ratio can be seen to increase with time, due to its preferential deposition from the mantle. This fact can also be used to date rocks which have a known initial $^{87}Sr/^{86}Sr$ ratio. Strontium can also be used to show that seawater rather than rainwater is reacting with intruded rocks.

Samarium (Sm) decays to neodymium (Nd), using a process of alpha decay (from ^{147}Sm to ^{143}Nd) which has a half-life of 10^{11} years, about twice that of the Rb. Whilst this means that there is less difference in the isotope ratios over a given time, both Sm and Nd have the advantage that they do not react much with water, so they can be used for age determination in rocks that have been altered by interaction with water.

Again meteorites can be used to determine the initial $^{144}Nd/^{143}Nd$ ratios for the Earth. In this case the crust is depleted in neodymium rather than enhanced, but it is still possible to use them for age determination when only the initial $^{144}Nd/^{143}Nd$ is known.

If the ages given by the $^{87}Sr/^{86}Sr$ and the $^{144}Nd/^{143}Nd$ differ there is evidence of water interaction and/or crustal contamination of the magma as it rises through the crust. In this case the Nd age determination is likely to be more accurate. Evidence of this type suggests that the Skye granites suffered metamorphism to amphibolites, and that these were erupted with the later acidic intrusions along with remelted Lewisian basement rocks in the area. The unusual isotope ratios of the Skye basalts is also postulated to be due to contamination by earlier rocks, which were highly metamorphosed to granulites.

Near Iceland isotope ratios taken from deep sea cores show conclusively that the altered rocks were affected by seawater rather than meteoric water, as you would expect on an ocean ridge. Isotopes also vary between the different volcanic areas which are above subduction zones, showing how the seawater in the subducted sediments is carried into the subduction zones at varying rates, where the resulting reactions occur. This also helps to explain the highly explosive nature of volcanoes above subduction zones.

Discussion

Q Can you determine what fraction of the water interacting with a volcano is rainwater rather than seawater?

A I don't know of any examples where you can show that both types of water were at work.

Q You mentioned that rocks intruded at ocean ridges show some degree of contamination by rocks that contain water, ie continental material. Is there any other evidence to support this?

A Yes. The potassium, sodium and rubidium ratios show that some continental material, probably dissolved in seawater, has made its way into the ocean ridge material. The interesting problem is whether some of this contamination gets fed back to the mantle, or whether it is all erupted back onto the sea floor. If it does get back to the mantle this would suggest that the crust might be slowly renewed from remelted sedimentary material originally of continental origin.

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Conference 80 — A personal view

J. B. Wright

Sorry, this is a bit long. Never mind, you don't have to read it. I've set down what I found interesting, instructive or new, and tried to show some of the tie-ups between the different topics that were covered in the lectures and discussions. If you were there it may help you to consolidate your own ideas: if you weren't you may still learn something. Assuming you read it.

First let me re-emphasise the importance of these gatherings in terms of their educational value, their role as a central meeting ground for OUGS members from all over the country and their social function, viz. re-uniting old friends and making new ones. This is an appropriate point to place on record my thanks to the organisers for yet another superbly run meeting. Accomodation, food, timing, entertainment, visual aids, speakers, there was never a hitch. Efficiency was so high that a colour TV was available near the lecture room for addicts to nip out from lectures and watch bits of those so-called cliff-hanging Wimbledon finals! If the OU itself were run as efficiently we'd have fewer disaffected students.

The conference was entitled 'From Asthenosphere to Crust: a symposium on igneous processes'. An imposing title, and a difficult subject area. I intend no disrespect to either speakers or audience when I say that a number of people found some of the lectures tough going - I know I did! At a conference like this participants have widely differing backgrounds in the earth sciences, and what is familiar to some is totally strange to others.

Altogether there were eight main speakers, each allocated 1½ hours for a lecture plus discussion, and we had short contributions from three of the Walton Hall post-graduate students as well. Incidentally, my compliments to the people who chaired the sessions - timekeeping of lectures and discussions was impeccable, and that contributes more than you may realise to the success of such meetings.

Remember this is a personal view. I'm not going to just summarise the lectures, I'm going to explain what *I* found especially interesting and tell you about the new insights *I* gained (in other words, my ideas of what was useful and important are unlikely to be the same as yours - but that doesn't mean that mine are any better).

The first of these insights - of the kind that's so obvious you never see it until you're shown it - came near the end of John Wadsworth's beautifully illustrated tour of volcanoes in various stages of activity and erosional evisceration. He laid a map of the Hebrides over one of Hawaii. The size and spacing of the Tertiary magmatic centres of the former are very similar to those of the volcanoes in the latter. Yet Hawaii is 98% basaltic, whereas the Hebridean centres have a lot of granite as well as basalts and gabbros (the coarse-grained plutonic rocks are exposed because these are ancient volcanic edifices that have been deeply eroded). A question that has been much discussed over the years is: did those Hebridean

Tertiary granites come from remelted crust or from differentiation of basaltic magma? All sort of evidence has been brought to bear on this topic, including a vast battery of isotopic data.

But consider this simple observation: you don't find significant amounts of granitic (or rhyolitic) rocks associated with big basaltic volcanoes built on oceanic crust. You do find them associated with such volcanoes built on continental crust. My simple mind draws the conclusion that melting of continental crust has contributed a fair bit to the Tertiary granites in the Hebrides, and to other granites in similar settings elsewhere. So it should be no surprise to learn that the isotopic data are once more pointing to that very conclusion.

We learned that in the course of Mike Norrie's brilliant and mind-blowing review of how stable and radioactive isotopes can be used to study igneous processes and crustal evolution. It is a difficult subject and he made it as clear as anyone could wish for. He also picked up a theme that recurred throughout the conference, namely the importance of water in igneous activity. It's mainly meteoric water (rainfall to you and me) and seawater that gets into rocks along fractures and fissures, which is heated up by hot rocks and magmas and interacts with them chemically and isotopically (as well as being spewed out of the ground as geysers and hot springs in some places).

John Rea's clear and systematic review of igneous-related mineralisation reminded us that among the more obvious manifestations of this interaction are pegmatites and hydrothermal ore deposits. These are the products of selective concentration of elements by hot water-rich fluids late in the history of magmatic evolution. (I hope those people studying S266 this year noticed that this lecture gave a very useful summary of a substantial chunk of Block 3!)

But is water important only at a late stage in magmatic cooling? Ray Macdonald suggested that the answer is no, in a very stimulating contribution on the relationship between batholithic granites and large silicic (rhyolitic) volcanoes. In brief, when we look at igneous rocks we see crystals or glass, which are the products of a silicate *melt*. The volatile phase - mainly water - has gone. That helps to explain the emphasis we traditionally place on crystal-liquid fractionation in cooling magmas as a way of producing a wide range of rock types. But, in these huge acid volcanic structures, there is geochemical and mineralogical evidence that a water-rich volatile phase is a lot more important as a means of shifting elements about in the magmas than most people have hitherto been inclined (or led) to believe.

We might, in fact, have been led to such a conclusion by simple extrapolation from observations of the kind so graphically and grippingly supplied by Peter Francis of the Mount St. Helens eruption earlier this year. There's obviously a lot of water inside a volcano. Occasionally it erupts with catastrophic and perhaps tragic consequences, when pressures inside exceed the weight of overlying rocks. In between eruptions the water doesn't just sit around doing nothing - it is busy mobilising and re-distributing elements in the upper parts of the magma reservoir(s) and surrounding rocks.

Karl Gronvold told us more about the role of water in magmatic processes, particularly in relation to the way partial melting and magmatic mixing can be just as effective as magmatic fractionation in producing a diversity of igneous rocks. Using English a good deal better than that spoken by many people whose mother tounge it is (and how many among us can pronounce Icelandic words, let alone speak the language?) he showed us what it's like to live on a constructive plate margin. If you didn't come to Nottingham here's a nugget of knowledge for you: to pipe water and/or steam between the eastern and wetern sides of the central zone of rifting in Iceland is to pipe water between the European and American plates! As the plates separate the pipes will break, and we were shown pictures of experiments with flexible (stretchable) piping. Actually I don't myself see how that's going to make much difference, because the separation of the plates is not a steady process. It's spasmodic, as you may recall if you've ever seen TV02 of S334. Rates of crustal spreading are conveniently quoted as *averaging* a few centimetres a year. But it would be more realistic to speak of metres per 10^2 or 10^3 years. The axial zone of rifting is not a single narrow chasm, it is a broad belt that may be 10-20km across, perhaps more. It is certainly that wide in Iceland, and there's evidence of similar widths along most of the world's active oceanic ridge system (of which Iceland is the only portion that's above sea level, remember).

Rifting occurs at unpredictable times and places within the central zone (well, it's predictable on a timescale of months in the sense that you can see it coming, but you can't make long-term predictions about where or when the next one will be, not yet anyway). What's more it's sudden: a crack 1-2 metres wide and many kilometres long can open almost overnight. Volcanism accompanies the rifting, which is hardly surprising. What *is* surprising is that much of the magma doesn't actually reach the surface. It moves *sideways* out of the magma reservoir and fills the newly formed fissures - perhaps some of the dykes in oceanic layer 3 are formed in that way.

It's a bit novel to think of dykes being formed by magma moving horizontally rather than vertically. But we'd already been introduced to the idea by Howel Francis, who recounted evidence from some older dykes suggesting that the magma moved along fissures rather than up them. His lecture was a valuable and thought-provoking review of the progress that has been made in understanding the mechanisms of igneous intrusion, especially larger sills. It is clear that there is still a long way to go - quite understandably really, nobody's actually seen a sill being emplaced!

But to return to Iceland and the information it provides about partial melting. It seems that as successive flows of basaltic lava are erupted along the central rift zone the older flows are buried progressively deeper in the crust. That's a result of our old friend isostasy. The *surface* of the Icelandic crust remains more or less at the same elevation, and so as the lava accumulates the whole pile subsides, as well as moving rather jerkily sideways away from the rift. As the lavas get buried they are heated up again due to the high geothermal gradient within and near the rift

zone. Huge volumes of meteoric water circulate through the cracks and fissures in the rocks, are heated up and re-emerge as hot-springs and geysers, supplying Iceland with its rich store of geothermal energy. The water also reacts with the basalts, and at a few kilometres depth the temperature is high enough for the rocks to be metamorhposed, first to greenschists and then to amphibolites. These are basically little more than hydrated basalts, and they will begin to melt at much lower temperatures than basalt itself. It appears that in Iceland the variety of igneous rocks (ranging from basaltic to rhyolitic in composition) can be accounted for by varying degrees of partial melting of amphibolite in the central rift zone and mixing with new basalt rising from the mantle. That's exciting, because for a long time the consensus view has been that crystal fractionation of basalt is the most important mechanism for producing intermediate and acid rocks in Iceland. But it's not *new*. As Ray MacDonald pointed out, a century ago or so Bunsen had suggested mixing of acid and basic magmas as a means of producing the spectrum of rock compositions. Plus ça change...

And that brings us back to granites and their origin. We were shown abundant evidence that silica-rich (acid) magmas, ie of rhyolitic (granitic) composition, can be produced by partial melting of amphibolites deep in the Icelandic crust. Basaltic rocks in deeper layers of oceanic crust are also extensively metamorphosed to amphibolite, because of interactions between seawater and hot rocks. Those amphibolites must undergo partial melting when the crust is subducted at converging plate margins.

Part of Geoff Brown's wide-ranging and challenging lecture was concerned with the broad classification of granitic rocks into S-type and I-type, which are respectively produced by remelting of crust (ie metamorphosed *s*ediments) and by *i*gneous processes presumed to originate in the mantle. To distinguish the two types you need evidence from field observations as well as mineralogical, chemistry and isotopes, and the distiction is not always clear cut. However, the Paleozoic granites of Scotland can be clearly sub-divided into an older (S-type) and a younger (I-type) group. As these are associated with the Caledonian orogeny they were produced above a subduction zone. What's more they were produced in large volumes, because these are big granitic batholiths. My question is: how much granite can you get from partial melting of amphibolite in oceanic crust at subduction zones? My answer is: not much, if only because it's doubtful if acid rocks make up more than about 5% of the total volume of Iceland. I-type granites in orogenic belts may well have a mantle component, but it's a fair bet that there is a lot of melted crust in them as well.

It would be wise to stop there, because this has gone on long enough. All that remains is to mention the research reviews, efficiently and entertainingly presented by Greg Reeves-Smith (rock types and structures in the Archean of India), Sally Barritt (radioactive elements and geothermal potential in Scottish granites) and Dave Rothery (interpreting satellite imagery of the ophiolites in Oman). A lot of people found these very interesting and informative, even if the jargon did get a little dense at times!

Hudeshope Beck

Pat Tye

On Sunday 30th September 1979 members from West Yorkshire and Greater Cleveland met in Barnard Castle at the pre-arranged time of 11.00hrs (by which time the day was half over for some of the members of the party!). We drove from there into Teesdale to see the Middle Limestone group of the Carboniferous Three Yard and Four Fathom Limestones.

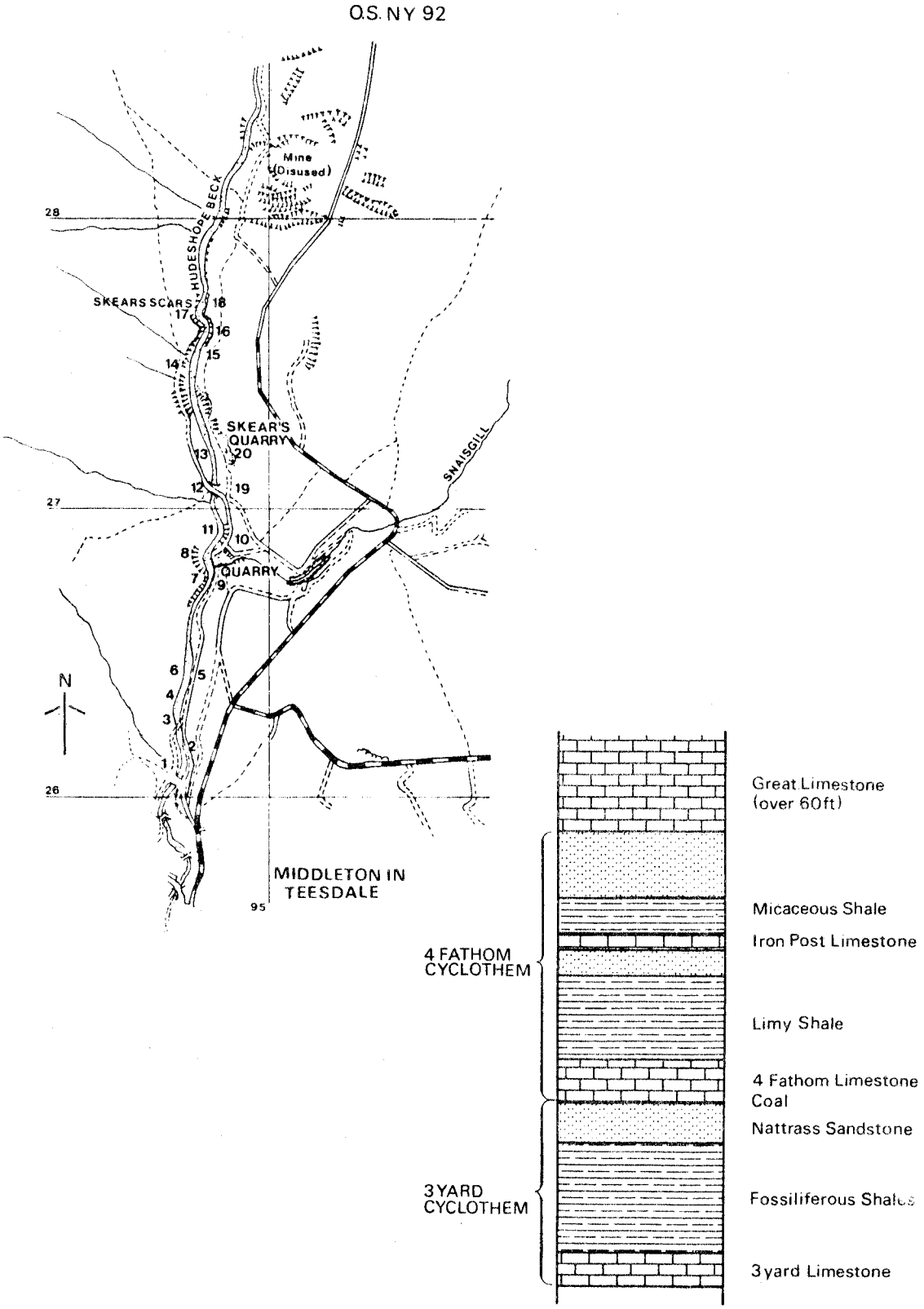
Richard Pepper, from Middlesborough, led a memorable field excursion which we would like to share with other OUGS members who may wish at some time to visit Hudeshope Beck. I am indebted to Richard for his help in compiling this field guide to the trip and for allowing me access to his notes, sketches and photographs.

Driving from Middleton-in-Teesdale along the Alston Road, you should take the right fork onto the Stanhope Road. After 300 metres take a left fork and then, after a further 60 metres (at GR261947), take the path on the left which leads down to a footbridge over Hudeshope Beck (which is marked as point 1 on the accompanying map).

Here the Three Yard Limestone forms a small waterfall. Cross the bridge and look over to the east bank of the stream, where fossilferous shales are overlain by thin limestone which is succeded by siltstones and fine sandstones. Between points 1 and 2 on the map the Three Yard Limestone can again be seen in the east bank, dipping gently to the north. The waterfall at 2 is also formed by the Three Yard Limestone, which is a grey, crinoidal rock with shale partings. Is there evidence of a fault? The dip of the Three Yard Limestone and its repeat at 2 suggests a fault somewhere here.

North of 2, and on the west bank at 3, the succession above the limestone can be seen. Look for: limestone, silts, fine sandstones, crinoidal limestone, dark fossiliferous shales and note the river level. You will notice that the sandstone and siltstones are thinner here than at point 1, and disappear beyond 3. Don't miss looking at the gravels in the river bed at 3 and 4 because they include examples of most of the sedimentary rock types in this local Carboniferous succession.

At 5 two normal faults bring to the surface underlying fossiliferous rocks. Which is the downthrow side? Look for undulations in the strata, which my young son called anticlines and 'sync-units'! Should you wish to see good examples of fossils look in the west bank at 6, a few metres upstream of the second fault, where you should find crinoids, brachiopods and bryzoa, the exposure being terminated by a north down-throwing fault. North of the fault the dark, unfossiliferous shales are again exposed. Beyond the west bank look for the 'growing stone'. It is a fine, calcerous tufa, originally fed from a now insignificant hillside stream associated with the fault.


O.S. NY 92
Mine (Disused)
HUDESHOPE BECK
SKEARS SCARS
SKEAR'S QUARRY
SWAISGILL
QUARRY
N
MIDDLETON IN TEESDALE
28
27
26
95
Great Limestone (over 60ft)
Micaceous Shale
Iron Post Limestone
4 FATHOM CYCLOTHEM
Limy Shale
4 Fathom Limestone
Coal
Nattrass Sandstone
3YARD CYCLOTHEM
Fossiliferous Shales
3yard Limestone

Between 6 and the waterfall at 7, unfossiliferous dark shales, siltstones and fine sandstones dip gently upstream, the waterfall being capped by a sandstone over a thin, fossiliferous limestone. At 8 there is a very prominent fault dislocating the siltstones and sandstone. Cross the road at 9 to see a fine example of a gannister at the entrance to an old quarry. Further up Snaisgill this gannister is succeeded by clay seat earth and carbonaceous shale, lying beneath the Four Fathom Limestone, which has been quarried at 10. Here small amounts of barytes, flourite and galena can be found.

Returning to Hudeshope Beck, 11 reveals yet another waterfall, this time formed by a capping of cross-stratified sandstone lying on a normal sandstone. Look carefully at this sandstone, which thins out noticeably on the east bank, yet thickens again downstream. This is a fine example of a small-scale channel sandstone which has cut through the siltstones beneath. Point 12 is immediately downstream of the stone bridge in the east bank. The base of the bridge is built on a unit of Four Fathom Limestone which overlies a a mid-grey, plastic clay. Look carefully for the fossil rootlets and thin coal seam.

A few metres downstream from the bridge, beyond a prominent fault, there is an anticline. Adjacent to the fault the Four Fathom Limestone is highly metasomatised, the major minerals being siderite and galena. Beneath and upstream of the bridge a further waterfall is formed over the Four Fathom Limestone. Can you find examples of tension gashes filled with calcite?

At 13 the beck flows over a platform of hard, calcerous mudstones which contain a good selection of fossils. Keeping to the west bank follow the path to 14, where an old mine adit can be seen. *Do not enter under any circumstance.* A further adit can be seen at 15, the two showing the NW-SE trend of the Wall's vein. It is from 15 northwards that we see a very pronounced gorge in the Great Limestone. The west bank (17) has been quarried, but look over to 18. Although the fault cannot be readily seen, compare the sequence of rocks in the gorge with those slightly downstream. Upstream sandstone gives way to the Great Limestone while downstream of the fault the sequence shows: siltstones and sandstones, dark shales, the hard limestone called Iron Post Limestone and further shales and silts.

The way north from here is very difficult, so retrace your steps and cross the bridge at 12 to take a look at the lime kilns at 19 before carrying on into Skear's Quarry at 20. The quarry has been used as a council tip, but it is possible to see a good exposure of the Great Limestone. Look for the fossil bands. It should be possible to trace six of these bands, which have been quarried for their decorative appeal. They are the Frosterly Marble used in Durham Cathedral and can be seen beautifully polished in the dark pillars there. If you look carefully there are good pockets of brachiopods to be found before returning home.

Once again I would like to thank Richard Pepper for his assistance. I hope you can find time to make the trip up the beautiful Hudeshope Beck, and remember - let me know when you are going because I may just want to join you!

Letters

Some observations on Geology and the Bible

Mr. Saunderson accepts, on the one hand, that the geological processes of the rock cycle operate 'so that mountains and minerals can be rejuvenated as required' (by whom?). He fails, on the other hand, to recognise that immense spans of time are required for these processes to happen.

There is a self-consistent body of evidence that the Earth has gradually evolved through thousands of millions of years, along with the life forms on it. Gradual evolution does not preclude the occassional 'catastrophe' ie large-scale short-term changes, such as volcanic explosions, floods or meteorite impacts. If you reject that self-consistent body of evidence, in favour of a 'special creation', you have to accept that the rocks and fossils - not to mention the other planets, stars and galaxies - are telling us lies, that the evidence has been 'planted' to mislead us.

Can you really put any faith in a God who could perpetuate a confidence trick on such a literally cosmic scale? If you can, then surely you can have no confidence in tomorrow's sunrise or the inability of pigs to fly and trees to walk. You abrogate consistency, and therby negate prediction and predictability. If fossils are the remains of dead organisms, if radioactive clocks are controlled by decay constants, in short, if matter is controlled by what we call physical and chemical 'laws', then the kind of 'creation' advocated by Mr. Saunderson has to be bunkum. You cannot have it both ways.

Either you can believe 'biblical' creation stories of the kind offered by Mr. Saunderson, and in so doing accept the universal anarchy implicit in that cosmic confidence trick, or you can accept an ordered (well, fairly) universe, in which things are reasonably predictable, except for human behaviour - and we're working on that. No Christian need feel in the least bit disturbed about a solar system that is about 4.6 billion years old and a universe that is perhaps as much as 20 billion years old - now that really *was* a Creation.

In conclusion, two questions and a comment. Do not the bits of the Bible which Mr. Saunderson quotes as 'evidence' occur in the Old Testament, ie before the birth of Christ and therefore pre-Christian? What is the reason for taking the base of the Carboniferous as a datum, eg for the transition from 'Perfect Earth' to 'Cursed Earth'? The real danger of these confused mixtures of prejudice and psuedo-scientific reasoning lies in our arrogantly homocentric stance. The belief that man is second only to God (any God) in the hierarchy of 'special creation' is the principle reason why the world has been beset by war, famine, pestilence and death for the last few millenia.

I hope that Mr. Saunderson's 'devoted band of OU students' setting forth to look for spurious evidence to support a fabric of inconsistencies will be a small one. If it

isn't I and my colleagues have signally failed in our efforts to inculcate even the rudiments of scientific reasoning.

John Wright
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Walton Hall

Editor's Note. Why is it that so-called scientists write letters like this? Apart from the fact that there are well documented evidence for pigs, and humans, having flown and for banyan and mango trees having 'walked', there is no physicist who understands the meaning of charm who would feel safe claiming that he can predict everything from physical 'laws' as they are currently defined, which puts an ordered universe in doubt. I, for one, am all for scientific reasoning, but based on fact and not confused mixtures of prejudice and psuedo-scientific reasoning of the type shown by this letter. Sorry John, but you'll have to do better than that to convince me that Mr. Saunderson's theories are not even worth considering.

In defence of the Orthodox Evolutionary Hypotheses

In 'Geology and the Bible' John Saunderson propounds an unorthodox and thought-provoking philosophy on topics of great interest and importance. Unfortunately he has relied more heavily than is necessary on unwarranted assumptions, sweeping generalisations and doubtful logic. These flaws weaken his case and I feel that the unsatisfactory areas need some comment.

In the section 'Evolution versus Special Creation', the second and third sentences seem to preclude Christians from believing in evolution - such people are necessarily atheists it seems! Having charged his argument with emotion, to then talk of normal, rational scientific or biblical debate, free of emotive overtones, is an abuse of argument.

Figure 1, by encapsulating prejudices in neat boxes, makes less sense (not more) of the variations in metaphysical speculation. My personal philosophy combines elements from various parts of a diffuse body of thought which John would artificially and arbitarily assemble into two chains - albeit with (limited) crossover links. Why should I not believe that both God and matter are eternal, and that God made the Universe? I certainly don't believe that the Universe has always existed, so why should I accept that premise along with the others that I do believe?

Turning to 'An Evolutionary Theory' (p17), I am not sure about evidence of evolution in historic time, the time involved is so very short - but what about Darwin's Galapagos finches? On the fossil record I feel I am on stronger ground. No important transitional forms? How about *Ichthyostega*, a late Devonian amphibian, but with cranial and post-cranial homologies to rhipidistian fishes like *Eusthenopteron*, with the even more transitional (but less well known) *Elpistostege* lying somewhere between the two (Romer, p87; Chanig, 1975, p61; Chanig, 1979, p82).

Then there is *Archaeopteryx*, a bird of sorts, but so like a coelurosaurian dinosaur that the 1951 Eichstätt specimen languished for over 20 years as just another *Compsognathus* until someone noticed the feather impressions! (Chanig, 1975, p129; Chanig, 1979, p139.)

The transition between fish and terrestial tetrapod, dinosaur and bird, are fundamental and important to zoology. From the human point of view another crucial transition shows in the Triassic therapsid cynodonts and bauriamorphs, which are thought to have been endothermic, furry reptiles. This description puts them very close to the beginnings of the true mammals, like the only slightly later *Morganucodon* (Halsted, p26). Coming way down the vertebrate evolutionary scale to even more fundamental changes, there are the calcichordates, lying somewhere between the echinoderms and the chordates, with connections to the acraniates, tunicates and vertebrates (Jefferies and Lewis, p307).

To return to Mr. Saunderson, his arguments about dating are somewhat disingenuous. 'Cambrian, Ordivician, etc' have always been largely biostratigraphically based and display a relative chronology only. The dates now shown next to them are not based on evolutionary criteria but on radiometric dating, as Zeuner makes clear (Zeuner, pp1-5). To use the known, recognised (and now largely calibrated) anomalies in short-term radiocarbon dating ($<5 \times 10^4$ years) as an excuse to summarily dismiss potassium-argon and other non-biologically dependent radiometric chronologies is really rather absurd.

I refrain from direct comment on 'A Creationist Hypothesis': a personal philosophy is to be respected and needs no rationale. However, as a comment on a common failing, I do wish that people would not assume that the dinosaurs became extinct because they were too big (for Noah's ark in this case). Dinosaurs came in many shapes and a very large range of sizes - from over 15m tall, and perhaps 100 tonnes mass, down to the size of a thrush and a mass of a few grammes (Chanig, 1979, p112). Who says they are extinct anyway? I suppose that dinosaurs *sensu stricto* are no longer with us, but archosaurs live on as birds (and crocodiles). I sometimes wonder if man's prediliction for slaughtering his 'feathered friends' is belated revenge for the 140 million years or so during which the birds' ancestors kept man's ancestors down to a minor, furtive role in terrestial ecosystems.

Passing on to John Saunderson's 'Conclusions', whilst many rock sequences are formed fairly rapidly, detailed study of geological evidence as readily shows long, slow accumulation of sediments - for example, the Solnhofen lithostraphic limestone, the Chalk and the many 'winnowed' bone bed deposits and thick evaporite sequences. Creation's case is not especially favoured by sedimentary evidence, and to suggest the opposite is to detract from the logic of one's arguments.

Overall, therefore, whilst John's contribution is intriguing and stimulating, he has allowed some doubtful material to creep in, and the use of the 'atheist' and 'radiocarbon' ploys casts some doubt on the objectivity of his reasoning.

REFERENCES
Chanig, A (1975). *Before the Ark*, BBC, London.
Chanig, A (1979). *A new look at the Dinosaurs*, Heinemann, London.
Halstead, L. B. (1978). *The Evolution of the Mammals*, Peter Lowe, London.
Jefferies, R. P. S. & Lewis, D. N. (1978). The English Silurian fossil *Placocystites forbesianus* and the ancestary of the veterbrates. *Phil. Trans. R. Soc. Lond.*, B282, 205-323.
Romer, A.S. (1966). *Verterbrate Palcontology*, University of Chicago Press, Chicago (3rd edition).
Zeuner, F. E. (1950). *Dating the Past*, Methuen, London (2nd edition).

Paul Clasby
Lymington

Editor's Note - again! Now that's what I call a convincing, scientific argument. Paul even thought enough about his letter to supply a separate list of those nasty fossil names, in capitals and well spaced out so that it could easily be used. Its that sort of thought that editor's really appreciate (hint, hint!).

Furthermore

Dear Sir,
I write in response to J. W. Saunderson's article 'Geology and the Bible'. I must deplore the patronising, biased, confused (and confusing) nature of this article. I particularly resent the pseudo-scientific format which, in my experience, seems an inevitable feature of articles on this type of subject. I am afraid that 'Geology and the Bible' is crammed full of unsupported (and often unsupportable) statements, over-simplifications, ommissions and terms which remain undefined.

Mr. Saunderson is in error in his synopsis. The Bible is *not* a method of finding the truth, but a statement of religious belief (ie faith, which is a subjective matter). Let us, here and now, get it quite clear that the concept of evolution is not a theory. The process of evolution is an established fact. Naturally there is more than one theory concerning the 'fine detail' of the mechanism of evolution, and there is still much that is uncertain. This does not detract from the essential truth of the evolutionary concept.

I would like to take issue with, as examples, just one or two of the points raised. Mr Saunderson states that the number of students becoming christians is increasing, and that those students are regarding biblical statements more literally than formerly. I would like to ask how he can possibly know this. Has a survey been conducted? If so, it must have been a rather sophisticated one to enable Mr. Saunderson to make these conclusions.

The article's next heading is 'Scientific method versus the Bible'. Scienblee'. Scientific method is a tool used to investigate, in consistent and clearly defined procedures (to scientists), the workings of the Universe in general, but often the Earth in particular. The Bible is not such a tool, and I therefore dispute the veracity of any comparison between the Bible (a book of faith) and scientific method (investigative tool). Further, scientific method is suitable in studying any

topic which allows itself to experiment, observation and modifiable inference. It is, therefore, ideal, contrary to Mr. Saunderson's idea, for investigating topics such as 'the origin of matter'. It may well even be ideal for investigating the topic of 'God', but this depends on how one defines the term. The Bible, furthermore, certainly *does* have something to say about the origin of the Universe. Unfortunately a) such pronouncements are used as symbols (not literal truth) and b) any attempt to consider the Bible's 'science' breaks down because, not surprisingly, not much scientific information was available 2-3 thousand years ago. Finally, on this subject, Mr. Saunderson is quite right in saying that science and the Bible are not in conflict, but this is because they are too different to compare.

Mr. Saunderson makes two dogmatic statements in his paragraph 'Evolution versus Special Creation': "Christians accept as fact...." and "Atheists accept the theory of evolution with almost religious fervour....". May I point out that niether of these statements is generally true, and Mr. Saunderson has not the slightest evidence for making these assertions. The Bible's treatment of creation was not intended to instruct (ie provide factual information) on the subject of creation, but the emphasis is *religious*. The early writers of the Bible were trying to express the purely religious idea (not factual) of a 'divine' creator of all things, mainly to a very simple and quite often superstitious people. The only 'facts' of creation put forward by the Bible are clearly outmoded. There are, further, many atheists who know nothing whatever about the concept of evolution. Mr. Saunderson, yet again, has made an incorrect inference. Atheists are those who do not accept the concept of 'God'. This does *not* imply that atheists accept evolution as an alternative.

In the paragraph headed 'Biblical problems' (which has been treated with a superficiality rendering it virtually meaningless), reference is made to Hebrew being unsuitable for conveying precise scientific statements. I must once again point out that the Bible does not purport to convey such statements - it is a book of religion, not science. Hebrew is a most suitable language for conveying religious statements.

Finally I feel that the conclusions given are dubious to say the least. I do not argue about the fine detail of geological matter, but I am of the opinion that the article is generally not very valid. May I suggest a rather less biased book for further reading: *An Introduction to Evolution* by Moody.

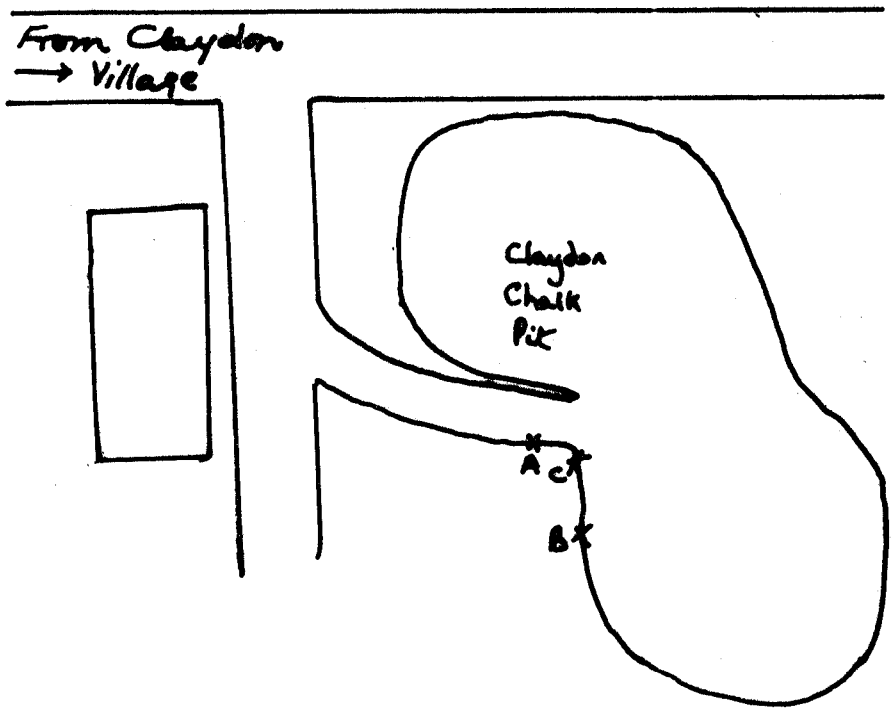
I make no apology for the length or tone of this letter of criticism. I have studied evolutional subjects for many years and am very interested in the relation between evolution (of life) and religion. I have found it most unfortunate that nearly every article and book I have read is biased and, quite often, misrepresentative of the concept of evolution.

J. V. Lane
London SE16

Branch Reports

Mushrooms and Cake won't be the same again

Dr. Peter Banham of Bedford College, London, spade to the fore and with a licence to dig, led 22 London Branch members wittily and at speed through the complexities of the 'Superficial Deposits of East Anglia' early last May. We started at Claydon Chalk Pit, 4 miles northwest of Ipswich (GR 136498). This was the first time most of us had seen Chalk being quarried by a disc-harrow! We visited three sublocalities within the pit, marked A, B and C on the sketch map.



At locality A Eocene sands and clays appear to overlie Upper Chalk in a normal 'layer cake' sequence. At locality B Upper Chalk is overlain by imbricated coarse pebble/gravel lenses, sands which show channel structures and contain matrix-supported chalk clasts (up to 5cm in diameter, indicating a short transport distance) and, resting on the sands, a 'raft' of detached chalk which rests on solid chalk at the left of the section and thins towards locality A. Above the raft can be seen contorted Eocene beds with a topping of the Anglian Glaciation. Interesting features were the 'festoon bedding' of periglacial origin and 'neptunian dykes', both in the surface of the rafted chalk. All these features occur above, under or around till deposited by an ice sheet, and the question asked was 'are they the result of glacial processes?'. (And answer was there none - Ed.)

At locality C you can pick out a coarse gravel/sand lense-like structure outlined by strongly iron-stained sands. This is probably an Alpine-style recumbent anticlinal fold, though close inspection reveals sand coarsening upwards below the central lense. Grading can, however, mislead and careful scraping will show the clays bending around the nose of the fold as they flowed under pressure, suggesting the probable anticlinal structure.

These features were probably formed during the roughly southward movement of the Lowestoft Ice Sheet, a temperate ice sheet in which freezing and thawing occurred regularly under the central ice and marginal thin ice froze directly to the bedrock. The ice-rock contact was stronger than the forces within the ice and this, combined with pore water pressure in the underlying sediments and glacial movement, caused 'lift-off' in the upper part of the sequence, leading to 'rafts' being formed and the deformation of the surrounding clays and sands.

Stunned by this instant immersion in glacial thinking, and covered in white chalk dust, we moved on to Neutral Farm Pit, Butley (GR 372512). This is where we started our collection of 'type locality fossils' for the weekend. Neutral Farm Pit is the type locality for the Butleyan, one of Harmer's three stages of 'Red Crag', the earliest Pleistocene deposit. It rests on London Clay (not visible here) and in other places is capped by Lowestoft Till. 'Crag' is a local word for any shelly sand. The rich red colour is iron staining, probably because of erosion of the iron-rich London Clay. Here they are truncated foreset and bottomset beds. The bivalves are for the most part in the normal 'way-up' position for disarticulate shells, this being especially noticeable in the imbricated central beds of the section

In the basal large-scale current bedding some of the bivalves are up-turned, possibly by eddy action on the foreset beds. The shelly layers appear to die out above the imbricated layer, probably as a result of secondary leaching as the beds approached the surface. Dixon postulates two divisions, deeper water at the base and shallower above, with possibly more variable current conditions in the upper part. There is evidence of changing current direction in the upper beds.

A rather interesting modern erosional feature was discovered in one gully to the left of the main face, where a series of sand pedestals about 5cm high were found to each be capped with a bivalve shell.

We lunched in Snape and sampled the local ale, Adnams - thoroughly recommendable. Fortified, the waggon train rolled on (well just imagine eleven assorted vehicles travelling the length of Suffolk and Norfolk - and the convoy only broke once!).

Next stop Corton Coast Section (GR 542982) to view our second type locality, that of the Anglian (Lowestoftian) Glaciation Deposits. Until 1971 this was regarded as the full Lowestoftian sequence and was the key locale for demonstrating the formations low in the Lowestoftian and also the occurrence of the sandy, clay-rich Norwich Brick Earth (Till) below the Lowestoftian Till, indicating a post-Cromer Forest Bed of pre-Anglian age. In 1971, however, a combination of storm action removing the sand dunes and a mountain goat-like student of Peter

Banham's (there is always one isn't there!) revealed three new units overlying the existing sequence. These were some Late Anglian Hoxnian Sands with associated gravels, which lay above the Pleasure Gardens Till, a typical flow till, and the Oulton Beds, a series of laminated, lacustrine clays which are varved in places. (The Pleasure Gardens Till show the problems of using geographical names for lithostraphic units when you run out of local villages!)

Our walk back along the beach was enlivened by the distant prospect of a naked male on the naturist beach (the sun *was* shining but we were all wearing anoraks, 2 or 3 sweaters, woolly hats, scarves, etc) - but, alas, Les did not have his telephoto with him!! Can anyone explain why the notices on the beach said 'Gentlemen may be totally unclothed on the beach but must don swimming trunks before entering the water'! (Several suggestions were made, but none seemed totally satisfactory.)

Next we visited the Happisburgh (pronounced Haysborough!) Coast Section (GR 380311). This was our last view of the 'layer cake' of glacigenic deposits - after this they became rather deformed. In this case they were Lower Anglian North Sea Drift deposits showing the standard undeformed sequence of beds which futher north are involved in the 'Contorted Drift'. This was our third type locality for the day!

Features included 'loadcasts' up to 1m in diameter and depth, where the base of the Intermediate Bed 'loads' into the First Cromer Till below, 'flame structures' where sediments of different particle size, water content and viscosity force their way into another bed, and the generally contorted nature of the Intermediate Beds.

We then drove to the Old Red Lion Hotel in Cromer, a most comfortable establishment with a long geological connection. Reid, the first person to map the area in the 1870's and 1880's, stayed here, and Peter Banham brought some beautiful hand-coloured early geological maps for our evening 'session', which was accompanied by one of the 25 beers from the pump or the 29 bottled beers on offer! (A veritable geologist's paradise!) After chat, pleasant company and discussion of such things as where the 'rampant flints' in the tills were - as Pepys would say - 'and so to bed'.

Following an excellent breakfast of prunes, haddock and a vast breakfast grill, to name but three items on the menu, we set off for the first locality of the new day, the Overstrand Coast Section (GR 248411). By happy chance the contractors who were repairing the beach revements had made a new cutting down to the beach. Here we were to get to grips with the Contorted Drift in all its complexities. The chalk has been 'rafted' (internationally the rafts are 'floes'). Palaeontology identifies the rafts as comparable to the underlying solid chalk, so there is little lateral transport.

The Contorted Drift consist of sediments of the North Sea Drift and the First, Second and Third Cromer Tills, all much contorted by two major fold phases, the chalk blocks being rotated in the second phase. Up the chalk cutting one can see the chalk rafts overlain by a conglomerate of derived flints, which fine

upwards into the Gimmingham Sands with adjacent Intermediate Beds and Second Cromer Till in their correct positions. Walking back along the sea defences, looking up at the cliff, the Contorted Drift lives up to its name. We had to walk carefully as there was a 'big sea' running.

The next stop was at the West Runton Coast Section (GR 185432) to view our fouth type locality, for the Cromerian Interglacial Stage. At ELWS (those who have done S2-3 will know that means Extreme Low Water Spring), and with an offshore wind, the underlying chalk is visible as a wavecut platform. At the back of the beach, at the foot of the cliff, can be seen the Cromer Forest Bed series, a black, organic and fossil rich rock. The extremely nacreous shells indicate a fresh water origin and the lack of any structure indicates lacustrine origin, as does the peaty nature of the deposit. The fossils include bivalves, an abundance of gastropod and vertebrate remains, including vole vertebrae and teeth, and fossil wood. The literature indicates a mixed deciduous forest was flourishing on the banks. There are estuarine gravels at the base, fining upwards into clay. It is a marine facies at the base, fining into the fresh water sequence.

The end of the Interglacial period does not occur with the Cromer Forest Bed as one would expect, but can be detected, using a microscope, 2-3m higher up the sequence. Here the sands become barren (having passed through a lower half rich in coniferous forest pollen) and the till overlies the sands, indicating a glaciation, i.e. climatic conditions deteriorate up sequence.

Walking further east along the cliff you reach the so-called 'Sand Basin', which has been controversial in the literature since about 1845. One of the interpretations was that it is a 25m deep 'valley fill', i.e. an erosional feature. The evidence contradicts this as there are conformable laminations on the valley sides, no regular valley floor slope and the plan is pseudocircular, not linear. Hence the so-called 'mushrooms' of the title, where the overlying Gimmingham Sands have loaded down into the underlying Contorted Drift, the clays of which they are formed having flowed outwards to the margins without completely breaking. These can be termed 'mega loadcasts'. These structures are the result of loading sands of irregular weight and strength over and into plastic clays, and they are linked with the second phase of the Contorted Drift.

Along the cliffs you can also observe many chalk rafts. A 'way-up' criterian for the rafts is if they show the Weybourne Crag, a shelly marine facies of the Cromer Forest Bed Series, at their base they are upside down. The margins of the chalk rafts are sheared, and fractured lenses and strips can be seen enclosed in the more plastic clays.

An added source of interest for some of us was the colony of fulmars nesting on the cliffs, wheeling and gliding on the up-draughts. The weather had deteriorated so we repaired to Sheringham for lunch in the Two Life Boats. Upon emerging one of our number was christened by a passing seagull. Its amazing what you put up with in the pursuit of science!

We re-assembled at the car park next to the North Norfolk Railway and set off to look at geomorphological features from Telegraph Hill on Kelling Heath (GR 103424). According to the geomorphological approach this is a flat-topped hill formed by meltwater streams flowing southwards. Muckleburgh Hill, on the seaward side, is a 'kame' (hat shaped hill) formed by a delta banked against the ice sheet. The topography is fresh and not much altered since glaciation. Geologists suggest that these land forms are interglacial and they are considered Wolstonian, not Anglian, because they show less dissected and fresher land forms. Land forms further east are older.

With the first stages of exposure setting in we drove off to see the Blakeney Esker in the Wiveton Downs Pit (GR 028424). This is a sinuous linear feature from which they are extracting gravel. It was deposited by a supra-, en- or sub-glacial stream, probably in an ice tunnel; the deposits slumped when the ice melted and the form is generally flat-topped and steep sided. The internal structure of the esker can be seen in this pit, where the flints show 'chatter marks' and are referred to as 'cannon shot' gravels. They are coarser at the top of the esker than at the base, this being typical of modern eskers in Finland. Periglacial festoons can be detected in the upper layers. Over the road the margins of the esker can be seen showing contortions which would be consistent with slumping. 'Ice wedge' casts can also be distinguished, infilled with overlying debris, the laminations at the edges being upturned because of the outward pressure of the ice.

There is another example here of possible 'mushroom' development, where the Marly Drift (about 100% $CaCO_3$ and virtually indistiguishable from the chalk) 'appears' in this quarry, again probably because of its different weight and strength over the plastic layer.

By now the cold wind had induced advanced exposure and we returned to the Old Red Lion for tea and biscuits. Macolm Roberts, our branch organiser, thanked Peter Banham on our behalf for an excellent weekend and presented him with a bottle of whisky. He responded by thanking David Hooper for making such an excellent job of organising the whole excursion, and as a token of our thanks David was presented with a bottle of sherry before we set off for our homes with Malcolm's comment to Peter fresh in our minds - 'Mushrooms and cake will *NOT* be the same again!'.

Diana Smith

West Midlands

At the time of writing we have completed five field trips, three of which have been held since the last report. On May 21st we visited an opencast coal mine at Cannock, where we were treated to a detailed study of the vast NCB opencast pit.

On the weekend of June 14th and 15th we joined the East Midlands group in North Wales. A very wet Saturday was spent studying the mineralisation of Parys Mountain on Anglesey. Mr. Ixer, our leader, went into very great detail and introduced some

new ideas on the local mineralisation. Details of new evidence that has recently arisen will, hopefully, appear in a later Journal. A drier Sunday was spent in Coed-y-Brenin, near Dolgellau, studying the mineralisation of the rocks under the forest, with particular emphasis on the gold in the hydrothermal veins. In spite of the weather an enjoyable weekend.

On June 29th David Thompson of Keele University led twelve members on a visit to Park Hall Country Park, Longton, Stoke-on-Trent to study the Triassic Bunter Pebble Beds. The park has been landscaped from a series of old gravel pits in the Bunter and the remains of old mine workings in the middle Coal Measures of the Potteries coalfield.

At the first locality the remains of a spoil tip from the 19th century Gainmore Pit allowed the group to investigate various of the Coal Measure rocks, including black shales with fish scales and larger fish fragments. In a 50m walk to Willifield Quarry the group crossed the unconformity into the lowest Bunter Pebble Beds. David revealed that their new name was the Cannock Chase Formation and that they were predominently sandstones. The rest of the morning was spent in Central Northern Quarry, one of the larger quarries off Hulme Road. Gravels here are overlain by cross-bedded sands, dipping gently southeast towards the Needwood Basin. Examples of faulting in the gravels were shown, and where individual pebbles had been turned from being normal to the bedding plane to being aligned with the dip of the fault plane, which had presumably occured while the gravels were still soft. Very many sedimentary features were observed, including cross-bedded units where each bed exhibited graded bedding sequences from gravel to fine sand. Energy regimes, river discharges, braided channels and meanders were discussed.

After lunch a pebble count exercise was undertaken. Among the samples were porphyries, vein quartz, liver-pink quartzite, various cherts, limestones and a decalcified sandy limestone with brachiopods. The latter looked remarkably like Ordivician and Silurian samples seen on the April field trip to South Shropshire!

The final locality visited, East Quarry, is bounded by faults which have limited the economic life of the gravel pit. Along the eastern face of the quarry the north-south fault can be easily traced. It is a normal fault, with a downthrow to the east which brings cross-bedded sandstone against the extracted gravels. Beneath the sandstones the gravels are too deep for economic extraction and the sandstones contain a high clay fraction, making them unsuitable for building stone or sand. David Thompson was thanked for his expert guidance at the end of our excellent day out.

The last two trips for this year are to the Peak District in September and Central Wales in November. Details are in the newsletter. Anyone interested in visiting the Chatterley Whitfield Mining Museum at Stoke with the Shropshire Geological Society should let me know so that I can make arrangements on your behalf.

David Franks

Mike's Geological Barbecue

This is an account of the weekend organised by the Walton Hall branch on 21st and 22nd June 1980. On Saturday some twenty people spent a day with Chris Wilson looking at the effects of changing sea levels on Middle Jurassic deposits in Oxfordshire. The earliest deposits seen were the Chipping Norton Formation at Charlbury Quarry. This oolitic deposit formed in shallow water. Above, the Sharps Hill Formation had clay layers derived from a land mass interspersed with limestone. We saw very clear evidence of frost heaving in the upper layers of the quarry.

We found the next part of the succession at Woodeaton Quarry, along with much 20th century detrius and several under-age motorcyclists. A shower of rain flushed an umbrella out of a rather distinguished rucksack! This quarry exposed the Hampden (Marly) Formation, in which we found plant roolets showing that the sea level had fallen by this stage. A rise in the sea level was indicated in the White Limestone layer above. This had been thoroughly bioturbidated so that no bedding was visible. Burrows, corals, gastropods and bivalves were found, but there were few deposit feeders, suggesting that conditions had become fairly marine. The sea must then have regressed because in the Forest Marble we saw fossil wood and a restricted fauna typical of lowered salinity. The latest formation seen was the Cornbrash shell beds, thought to have been deposited in more marine conditions.

We then adjourned to Mike Henty's farm, where we camped for the night. After a certain amount of puffing and blowing over the charcoal the barbecue was under way, followed by jovial and sometimes bawdy singing round the fire.

Sunday was spent at Chinnor Cement Quarry with Peter Skelton. We were enticed into a large and noisy building during a shower of rain by a cement worker, who told us about an icthyosaur which was being extracted from the quarry. We later uncovered, admired and photographed the rather mangled remains. For cement production 80% calcium carbonate is required. This is obtained by mixing the lower clayey layers with the purer upper layers. The under 10s in the party found many fragile ammonite fossils and limonite nodules. A lot of the shells we found had been squashed before being fossilised, giving odd shapes to familiar fossils. Bioturbidation had destroyed the bedding. We were unable to find any corals, but did discover that only one pub serves food on Sundays in Chinnor. After lunch a reduced party explored the upper part of the quarry. The nodules found were unusually thin chipolata shapes. A greeny layer at the top of a steep loose scree was identified as the Belemnite Marls, marking the junction of the Lower and Middle Chalk. Three children had great fun on the scree and still had enough energy to return to the lower quarry. At this point I was forced to retreat due to exhaustion from carrying a large quantity of wet chalk around on each boot!

Many thanks to Chris and Pete for such interesting trips and to Mike and helpers for a super evening. All in all a most enjoyable weekend. Sandra Simpson

Or as Hazel put it

we went on a weekend holiday and we went to some qarries. I found some brown Nodules and ammonites They lived in the sea. I found them in chalk rock we went to three qarries the first Day. then we went to a farm to stay the night. mike had a barbeque and one bonfire. I had cooked tomato and bread and tomato Not cooked. I went to bed at half past 12. The Next Day we had to get up at 10 o'clock we had to pack up our tent and then we went to a qarrie we saw a fossil swimming reptile under some plastic and then we went home.

Spelling and punctuation courtesy of Hazel Simpson, aged 7

Lake District Field Weekend May 1980

During the Mayday Weekend 19 members from the Oxford and East Midlands branches stayed near Keswick and studied the geology of the Lake District, continuing the previous years' study under the able leadership of Geoff and Joan Brown.

Our map shows that the Lake Distict is a glacially eroded asymmetrical anticline of Lower Paleozoic rocks which form an inlier, being completely surrounded by unconformable (almost horizontal) Upper Paleozoic limestone and sandstone. A further faulted inlier occurs as the Cross Fell Inlier to the northeast.

Saturday morning saw us looking at the relationship between the Borrowdale Volcanic series and the Skiddaw Slates it passes through, the medium grain size indicating it's intrusive nature. Ferro-magnesium pyroxines were seen in what was probably a plug in a feeder vent for a past volcano that has since been eroded away.

We then descended to Friars Crag on the shore of Derwentwater (GR264222), where below the Pleistocene drift deposits a contact between a dyke (?) and Skiddaw Slates was seen. There was little evidence of baking or disturbance of the slates. We walked along the shore, which is controlled by the harder dolerite on the east, and came to a fault where the dolerite had been moved westward. A well developed fault breccia could be seen, with associated veining. Erosion had occurred along the breccia.

We then drove south to Ashness Fell and perched on Falcon Crag (GR272205), from where we could see a great variety of glacial geomorphic features. Of particular interest was the silting up of the lake shown by the River Derwent meandering through islets and bars. We speculated on the lifetime of the lake!

We had lunch at Grange (GR253175) sitting on a slate roche moutonee. Between us we collected a fairly comprehensive set of Borrowdale volcanic pebbles from the river and terrace, covering most of the textures and compositions, before moving on to the Bowder Stone (GR254163), a block of volcanic agglomerate, estimated to weigh about 2000 tons, which had fallen from the cliffs above.

At Bowder Mine (GR254165), in the Borowdale volcanics, metamorphosed volcanic agglomerate containing green chlorite which showed sheen and cleavage was seen. High and low temperature metamorphism was shown by the mixture of quartz and calcite in the tension gashes. After driving south again to Seathwaite, we climbed 800ft up the west face of the U-shaped valley to investigate the unique graphite/haematite mines (GR235128). We did not find the actual mineral veins, but samples of the graphite and haematite could be collected from the spoil heaps. The mechanism for mineralisation is controversial. The bleached and lightened state of the lavas was interesting, the heavier minerals having been removed.

The Honister Pass looked magnificent as we drove over it in search of the Ennersdale Granophyre. We parked at Buttermere on the Hope Beck Slates and, after a mile long walk across the Lowes Water Flags, found the Ennerdale Granophyre at a waterfall in a stream section near the northwest end of Buttermere, on the south side of the valley (GR172162). This later Ordivician intrusion is a fine-grained pink granophyre.

The hot Sunday morning sunshine was enjoyed searching for graptolites in the Lowe Water Flags at Bishop of Barf (GR217264). A variety of sedimentary structures were seen, with anoxic conditions being shown by the abundant pyrites. Two *didymograptus nitidus* were found (aspiring fossil hunters please note!). Driving east to Ulleswater we found the western bank of the lake to be composed of a fossilised river deposit, the Mell Fell Conglomerate. Post-Silurian and unfossiliferous, it shows a wide range of clast sizes. Lunch was again taken at Shap Wells before we went on to spend the afternoon mapping the lithologies and unconformity at Blea Beck.

On Monday our first stop was at the quarry on Maulds Meaburn Moor (GR640140) in the middle of the Carboniferous limestone sequence surrounding the Cross Fell Inlier. The limestone here is very fossiliferous, showing good examples of many characteristic fauna, including corals, brachiopods and crinoids. A brief stop was then made at Hoff (GR665172) to look at brockrams of Lower Permian age. This conglomerate showed arid erosion features.

The afternoon was started at Swinedale Beck (GR685273), which also contains Permian rocks, in this case a mixture of water- and wind-deposited red, fine-grained sandstone. Bed thickness varied, as did the mica content, and some horizons had barytic cementation. A short walk brought an abrupt change of lithology. The Outer Pennine Fault had been crossed and the Brathay Flags had been upthrown to the surface. We then walked down the succession, a few people finding some Å2monograptus crenulatus on the way. The Cross Fell Minette, trending NW/SE, was found in a stream section, and seen to be intruding the Browngill Beds, which are locally altered. This mica-rich lampyphyre dyke is of Lower Devonian age and is associated with the Shap Granite group.

The next stop was at Knock Pike Quarry (GR687286), which is on a conical-shaped hill, one of a line of such Middle Ordivician features along the Outer

Pennine Fault. Good examples of acidic eruption products were seen, ranging from flow-banded fine-grained pale grey rhyolite to welded tuffs. Some lamprophyre dykes were also noted. The final stop was after a long climb up the impressive Cross Fell itself, past the snow patches to a mine at Great Dunfell (GR702318), which was a mere 2500ft above sea level! We had passed from the limestone into the Yoredale facies, passing the Whin Sill on the way. Barytes is mined here as drilling mud for North Sea oil exploration. Other minerals found included galena and sphalerite.

Our thanks go to Joan and Geoff for the preparation and leadership they put in to make this such an enjoyable and thought provoking trip.

Jane Randle/Ivan Foster

Irish Mist

This is a belated account of the OUGS National Field Trip to Ireland in Easter 1979. There were eighteen of us in the party, led by Malcolm Roberts, from all over the UK. Our introduction to Ireland was a drive from the ferry through the Dublin rush hour in pouring rain and darkness in a couple of mini-buses. Our culinary treat that evening was fish and chips at Clontarf! I mention these non-geological facts as a taster - things could only get better!

The first full day, Wednesday, was spent looking at the Leinster Granite with Drs. Con Gillan and Padhraig Kennan. The Leinster Granite is a Caledonian intrusion for which Rb-Sr and K-Ar mica ages of approximately 400 million years have been established. A significant feature of the granite is that there is sulphide mineralisation on the eastern side but not on the western. We spent the day looking at exposures that outlined one of the theories for the occurrence of the sulphides, starting at Killiney Hill, where we looked at pegmatites in the granite which contained spongemenes (or killinite) composed of quartz, albite and muscovite, the latter containing lithium. The lathe-like crystals of spongemene were clear and very pale green, and difficult to find. These pegmatites are older and contain a different suite of minerals to the younger sulphide-bearing pegmatites we saw later.

The next stop was at the beach at White Rock, where we loked at the schistose Garnetiferous Beds, which are suggested as a source for the sulphides. They were sedimentary ironstones rich in manganese. We saw folding in the quartzites which, it was suggested, was the result of soft sediment deformation, but it is also thought that these folds were tightened by plastic deformation during the intrusion of the granite. This is supported by the growth of clearly visible garnets which were formed in the interval between the initial folding and the tightening. These garnets are embedded in a matrix of granoblastic quartz with very minor mica, feldspars, magnetite and other accessories. We were also able to see andalusite crystals, which form starred patterns where they crystallised along the ex-

isting structure of schistosity. It was pointed out that the Garnetiferous Beds occur only on the eastern flank of the granite.

The next location was at Bray Head. The rocks here are not part of the day's general theme but are interesting in that it is difficult to explain them being where they are. They are the Bray Group, and microfossil analysis puts their age at Lower to Middle Cambrian. They sit on top of younger metamorphic rocks and it is suggested that they were thrust into their present position from the east. This theory is not generally accepted, but is the only way at present of explaining their position. The rocks are greywackes, grey-green in colour, and we could see evidence of their having been deposited by turbidity currents. They form graded depositional units and they are interbedded with quartzites which display similar sedimentary structures but which, studies have shown, come from a different source. We could see the quartzite is fine-grained and showed evidence of having been folded sino-depositionally.

The next stop was above Lough Tay. Here we could see pegmatites in the quartzite beds which differed from those we had seen earlier in that they contained lead and zinc sulphides. We were now close to the granite, at the inner edge of the aureole. The beds could be seen to have been intensley folded by the intrusion of the granite. They were full of manganese-rich garnets and, as with the White Rock exposure, there was evidence of folds having been present prior to the intrusion - possibly caused by some regional metamorphic event. The published data on these lead sulphides puts their age as considerably younger than both the granites and the nearby Avoca-type lead deposits. Dr. Kennan explained that he felt that the age determinations of the sulphides had not, perhaps, taken into account contamination by radiogenic lead from elsewhere. His feeling was that the sulphides were intimately associated with the intrusion of the granite. His suggestion was that the intrusion heated the groundwater of the country rocks, so leaching the Garnetiferous Beds which are recognised as being good source rocks, the sulphides only occurring on the eastern side, where the Garnetiferous Beds are. Another stop, just up the track and onto the granite, revealed that the granite is rotten at the edges but further in one can see the sulphide veins.

At Glenmacness, still on the eastern part of the intrusion, we saw changes in the granite from an adamellite to a more even-grained granite in the space of some four metres. We also saw more sulphide-rich pegmatites and areas of intense hydrothermal alteration. At the last location, back on the western side of the granite, we again looked at pegmatites, but they did not contain any sulphides, thus making Dr. Kennan's point. We thanked our leaders for an excellent day's outing and they then returned to Dublin while we headed in increasing darkness towards Tramore, our overnight stop. (Dr. Padhraig Kennan's paper on 'The origins of the sulphide deposits in the Leinster Granite', pp41-47 of Volume 1, 1978 of the *Journal of Earth Sciences*, Royal Dublin Society, provides full details if anyone is interested in finding out more.)

At Tramore we recieved a very warm welcome from our hotel. An endless supply of sandwiches and coffee was served up by a seemingly endless supply of

daughters! We also met Dr. Chris Stillman, who was to be our leader for Thursday. Before setting out in the morning he gave us an introductory talk on the Waterford area. The rocks of the region are almost entirely of Ordivician age, though there are a number of small but important outliers of Old Red Sandstone on the coast. It seems that during the Ordivician this area formed part of the southeast margin of the Iapetus Ocean and was the site of intense volcanic activity characterisitic of an area situated on the fragmented edge of a continental plate behind a developing arc-trench system. Localised early tholeiitic basalt volcanism changed rapidly to very extensive calc-alkaline activity, which produced a close intermixture of basalt-andesite-dacite suites with very abundant rhyolites. Towards the end of the volcanic phase there was a return to tholeiitic activity, with a few dolerite intrusions and some more alkaline intrusions.

Eruptions began with the outpouring of relatively gas-poor andesite lava into the submarine basin; this chilled and disintegrated in the seawater and, with the pyroclastic products of occasional, more violent, eruptions, built up two or more extensive shield volcanoes; turbidite-like mass-flow hyaloclastic units, probably triggered off by seismic shocks, are associated with the volcanic eruptions. Injected at shallow depth into the tuffs were abundant sills of andesite which pillowed and sometimes sagged into their partly lithified floors, or broke through the underlying tuffs in load casts. Large intrusions of pyroxene diorite with chemistry very similar to the andesites are also found, and these probably represent high level stocks crystallising from this same magma. This succession comprises the Lower Tramore Shale and Volcanic Formation.

The initial activity was followed by a pause marked by the deposition of the Tramore Limestone, then renewed deepening of the basin in early Caradoc times led to the incursion of turbidites. Further coastal instability, shown by the occurrence of seismites and slumping, presaged a new phase of volcanic activity (deposited as the Middle Tamore Volcanic Formation) that started with a voluminous eruption of acid vitric ashes, which reached their place of deposition as mass flows, and the further injection of andesite sheets. Rhyolites erupted explosively from a number of small cones which built their way above sea level and produced substantial sub-aerial tuffs. In contrast to the andesites the rhyolite eruptions were highly gas-charged and some ignimbrites have been reported. This rather full introduction was very useful because it partially enabled us to fit in each exposure to the overall picture.

We started out, in the pouring rain, feeling very knowledgeable and rather hung over from an excess of whiskey. The first locality we visited was Cullen Castle. Here we could see a very coarse epiclastic volcanic conglomerate, completely chaotic in fabric, unsorted and ungraded, with lithic clasts in a sandy or gritty ash matrix. The clasts were of rhyolite, dacite and andesite; many were angular and unweathered, which suggests that this deposit was formed close to the source of the fragments. The matrix was a shardy tuff in which the shards were vitric and were preserved in delicately curved and cuspate forms.

We next went to Garrarus Strand, where we saw more rhyolitic breccias and tuffs. Further round the beach we noted frequent andesitic intrusions into the volcanic clastics and shales, and saw how these intrusions seem to have been sunk into the sediments. This caused disturbance of the sediments and some pieces were caught up in the intrusion. These features suggest that the intrusions were contemporaneous with the sediments. Further on, a dyke was seen to be cutting an earlier intrusion; it had chilled edges suggesting that it was emplaced once the sediments had become solid. The base of the headland was seen to be a massive andesite and this, it was suggested, was a shallow chamber from which the magma was injected into the overlying sediments and tuffs. At one point we also noticed a fragment of Recent raised beach - about 4 metres above the present beach. This material looked as though it had just been deposited, yet on inspection turned out to be extremely well cememted and quite solid.

We then walked round to Lady's Cove. Here we could see vitric-crystal tuff sequences near the base of the Middle Tramore Volcanics Formation. The pyroclastics could be seen to be intruded by flow-banded rhyolites and by later andesitic dykes, which are highly vesicular but show no contact phenomena. There were many boulders of tuff lying on the beach. The chaotic nature of the ash was shown in places by the quite large fragments which could be clearly seen. The fragments, as at Cullen Castle, were very angular and unweathered.

We then went inland again to visit the Dunhill Castle Quarry. The back wall of the quarry displayed a really impressive sequence. There was a series of tuffs, each one grading from lapilli tuff at the base to fine tuff at the top. The tuffs were poorly sorted, with even the coarsest containing a large proportion of ash. The obvious inference is that each unit represents a separate ash fall, the sorting being carried out in the vertically erupted ash column. The fine tops to the beds had sorting and bedding features which suggest that the tuffs fell into water, and when the pyroclastic shower ceased for a time the finer material settled and the tops of the beds were reworked. A further obvious feature was the scatter of blocks of pumice and rhyolite, which were concentrated in the fine tops. It was suggested that the pumice gradually became waterlogged and finally settled out of the water. The rhyolites were probably the initial material from a fresh eruption. The very clear load markings in the tuff where these rhyolite blocks had landed on the still soft tuff support this explanation. With an eye-glass one could see that the lapilli consisted of compressed pumice, vitric shards, small rhyolitic lithics and abundant accretionary lapilli of very fine rhyolitic ash. The latter form in the air column when small hot particles stick together and get coated in even finer ash.

After taking over a pub - suprisingly empty for Ireland - to eat our lunch and drink several Guinesses we set off back to the coast at Stage Cove. We examined the Tramore Limestone, with its fossil casts, and saw where it is faulted up against amygoidal andesite. The fault plane is heavily mineralised with pyrite and chalcopyrite, and constituted one of the principal mineral lodes mined in the nineteenth century. Further along the beach another fault brought massive columnar jointed rhyolite down to beach level. The whole sequence was seen to be

dipping gently northwards. We returned to the buses and journeyed westwards to Bunmahon Head, where we looked first at the almost vertical Red Bed facies, conglomerates and coarse and fine sandstones, which displayed many good bedding features and sole markings. The base is marked by an angular unconformity with the underlying andesitic lavas, pillow breccias and tuffs of the Lower Tramore Shale and Volcanic Formation. An interesting feature of this location is a basaltic column which sticks up on the beach and is known as Lot's Wife. The coastal scenery is also very wild and exciting here - the rain had stopped for a while and a watery sun shone on jagged rocks, wind-whipped seas and Atlantic breakers. The whole trip was worthwhile just to stand on that beach for half an hour.

Enough of the romantics - back to the geology! Our last location for the day was Ballycraddock. Here we saw a fine flow-banded sub-horizontal sheet of rhyolite with a strong concentration of lithophysae near its upper surface. These are also termed spherulites and, in this case, were small (0.5 to 1 cm) and had a radial growth of quartz and feldspar within an ovoid skin. The flow-banding within the rhyolite was planer and in places highly contorted. Nearby we saw a small andesitic vent, with a vent agglomerate and an arcuate band of coarse tuff suggesting the remains of an ash cone. The vent rocks had been hydrothermally altered.

The general picture presented at the beginning is very difficult to follow in the field and it is only with careful mapping and correlation work that it can be arrived at. Our day had at least shown us the sort of deposits that volcanism can bring. We thanked Chris Stillman for an excellent outing as, despite the almost continuous rain, he had made it a most interesting day. He, in turn, said he had thoroughly enjoyed himself and found it refreshing to have students keen on what they were doing! For anyone interested in this area there is a field guide published by the Irish Geological Survey. Dr. Stillman has written the part on the Waterford Volcanics and I confess to having supplemented my field notes with information from his guide.

That night we stayed at Limerick, ate heartily, drank moderately and went to bed happy. On Friday we drove to the west coast, where we led ourselves, starting at the Cliffs of Moher. These 600ft high cliffs form a sheer drop from a flat, rolling meadowland. At the base are shales, which are followed by hundreds of feet of flagstones, a thick yellow sandstone and, at the top, the black Moher Shales. These are all Upper Carboniferous (Namurian) in age. An added attraction is the use of the Moher Flags as uprights along th edges of the paths. These contain a profusion of mollusc grazing trails. After a quick look at O'Brien's Tower, which sits atop the cliffs, we went on to Fisherstreet Bay.

The rocks here are composed of the Clare Shale Formation, which includes goniatite-bearing shales. Most of the party moved along the beach to look at a feature termed the Fisherstreet Slide whilst the remainder stopped to look at the fossiliferous shales. These can be split quite easily to reveal flattened goniatites,

brachiopods, bivalves and pectens. Kirsty Dixon found the best fossil though, a trilobite. The Slide is where there was mass movement of sediments resulting in complex folding and thrusting, and the development of flow cleavages. The operative word is complex because there is a profusion of structural features.

From the Slide we went on to the Burren. This is a large area of limestone where there is terrace after terrace of limestone pavement stretching as far as the eye can see - a vast area devoid of soil but having many interesting plants. The Burren is a botanists paradise, being a meeting place of plants from the Artic, the Alps and the Mediterranean, all flourishing in the mild climate and the lime-rich environment provided by the Burren. Some of the plants are a hangover from the last Ice Age. Unfortunately we were too early in the year to see even the spring plants, but we did spot some saxifrages. The limestone beds are almost horizontal (there is a slight dip to the south), as were the beds making up the Cliffs of Moher. Further south beds are folded, and later on it was suggested to us that possibly the granite we were to see in Galway extends under the limestone and other beds and formed a base resistant against folding. Anyway, we went inland and there saw other karstic features, including poljes. These are large, closed depressions, the largest being the Carran Depression which we visited. This is over 200 feet deep and is the largest in the British Isles. We drove on from here to a farmyard, where we left the buses and started to climb. After a long climb, in the hot sun, for this was the sunniest day we had in Ireland, we got to Kilweelran. Here we found a large deposit of what is stated to be flourspar, formed where flourine has combined with calcium in the limestone. The crystals found did not exhibit the usual cubic shape and it was postulated whether these could be pseudomorphs of the calcite, as they looked just like the purple calcite. We returned to the buses and drove to Galway, where we were to stay for the next four nights.

Unfortunately the next three days were dogged with some bad luck. First we discovered that our leader was laid flat with a slipped disc. Secondly petrol became almost impossible to obtain. Luckily Paul Ryan, our leader, had made some field notes and we were able to use these for the first two days. The petrol was more difficult to overcome and it limited what we were able to do and see.

On Saturday we looked at the Main Galway Granite batholith, which was emplaced at the end of the Silurian era. An unusual feature of the pluton is that it is made up of several ring complexes that are reverse zoned, each having a granodiorite core and an alkali-granite margin. Three main granite types may be distinguished; the Carna Granite (a biotite-hornblende granodiorite), the Errisbeg Townland Granite (a K-feldspar megacrystal adamellite) and the Murvey Granite (an alkali granite). The reverse zoned nature of these intrusions has been accounted for by Leake as being the result of initial crystallisation of the granodiorite, followed by differentiation to produce the adamellite, the filter pressing of the adamellite mush by stoped blocks of country rocks causing the squeezing out of the marginal alkali granite. The initial $^{87}Sr/^{86}Sr$ ratio of this and all other Galway Granite is low and they are believed to have been developed at or near the crust-mantle interface during the Caledonian orogeny and to have ascended to their present level along major faults.

So, armed with Paul Ryan's field notes, we set out. We stopped first at Lough Nahogo, where there were several shallow quarries by the roadside. Here we saw the pink sacchoroidal Murvey Granite, the most acidic of the three types. The granite occurred here as a screen separating intrusive centres: it also occurs at the margins of the granite. From here we went ot Costelloe where, in a freshly blasted road cutting, we found the Carna Granodiorite and the Errisbeg Townland Adamellite. They both exhibited good flow-banding and were in turn cut by a felsite intrusion which also had flow-banding near its margin. Over the joint srfaces of both the felsite and the granites we found a thin smear of molybdenite; like a layer of paint. We also found chalcopyrite both on the joint surfaces and in the granites.

We next drove on to the island of Lettermullen, where we parked the buses and went over a causeway to another island, Furance. I confess I found the scenery a bit desolate here, particularly in fine rain. There were boulders, bare rocks and bogs. It is all very flat and a complete contrast to the previous day's scenery. Our trip here was to see the margin of the granite, in this case the Errisbeg Adamellite. The granite has a narrow chilled margin with the contact-metamorphosed basic volcanics of the South Connemara Group. We found this but were unable to see any sign of where a wedge of Murvey Granite is supposed to be emplaced along the contact zone. We retraced our steps and drove to near the village of Carna. Here, naturally, we could see the Carna Granodiorite. By walking some 500m northwards we saw the Errisbeg Adamellite and a futher 1km northwards brought us to the Murvey Granite. This demonstrates the reverse zoning of the main Galway Granite mentioned earlier. The Murvey Granite was in contact with Dalradian migmatites, which are prominently banded.

Our last stop for the day was near Moynus. Here we saw the Dalradian migmatites forming a thin screen between the Errisbeg Adamellite and the Roundstone Granite. Both plutons are composed of similar medium-grained granite and it is suggested that they are comagmatic. The migmatite screen has been extensively stoped and some large blocks, up to hundreds of metres in length, were visibly enclosed in the granite

On Sunday we looked at some of the metamorphic rocks, but we could not look at all we had intended to because of insufficient petrol. Our first stop was at Lough Nahaslean. Here we looked at migmatised metasediments and were supposed to see red garnets, sillimanite and waxy-green cordierite. We failed to find the first two but did find the third. Our next stop was almost at the Twelve Pins of Connemara, an imposing range consisting of Precambrian quartzites. Interestingly these rocks have proved far more resistant to erosion than the younger granites. We stopped about 2½ miles from Maam Cross to look at the Boulder Beds. These were exposed in some hummocky ground at the base of the Leckarea Mountains. Within these beds we found some highly deformed clasts of granite and dolomite, about 10cm long. The most interesting feature here, however, was an outcrop of skarn. This was reached across a stretch of boggy ground that nearly claimed several victims. Not being familiar with skarn or garnets I asked a

more knowledgeable member of the party, Tom Patterson, where the garnets were, only to be told I was standing on them! The garnets were of the brown almandine type and were mainly in a large amorphous mass. However, several large well-formed crystals were found, as were some good specimens of epidote, chalcopyrite and pink quartz. Adjacent outcrops showed skarn with variable portions of garnet and epidote replacing the country rocks. The origin of the skarn is unknown.

Our last stop for the day was at Claggan Quarry, which is in the staurolite zone of the Connemara Formation metasediments. Here we found some beautiful specimens of pink andalusite pegmatite. We also looked for pinitized cordierite poikiloblasts which were supposed to have been there, but we could not find any. (I would not have recognised them if we had!)

On our last day in the field we were led by Paul Ryan, who kindly climbed off the board on which he had been forced to lie. Unfortunately, because we had so little petrol, we were confined to the immediate area of Galway. The weather had cleared up and it was very pleasant to start our day on the beach at Silver Strand. Here we looked at some cross-sections through a drumlin. Paul ran through some of the theories concerning Ice Ages. One he mentioned suggested that the periodicity of Ice Ages was 200m.y. This, it was suggested, was related to the movement of the Earth through the galaxy, where we regularly passed through a 'dirty' bit that absorbed the Sun's radiation and so cooled the Earth. The awkward part of this theory is explaining the inter-glacials within an Ice Age. We looked at the material in the drumlin, which was quite solidly cemented by calcite. There were pieces of very smooth limestone and other local material - suggesting that the glacier that formed the drumlin was only a local one. The direction of movement of the glacier was from east to west. The material in the glacier was poorly sorted and chaotically deposited.

As an interesting aside Paul talked about the limestone algal reefs having high sulphur content and how this helped to trap the lead and zinc in hydrothermal fluids coming up faults and fissures. This has led to reef limestones being exploited for lead, etc; as examples of which he drew our attention to the Nevan and Tina mines. After a snack lunch on the beach we moved back to Galway.

Our next stop was an outcrop of rock in the middle of a green in a council estate! We immediately attracted the interest of a group of young boys who followed us around peppering us with questions, some of which we could answer! The rock was Murvey Granite and Paul elaborated on the suggested origin, how it is an eutectic granite, formed in the liquid phase and squeezed out when most of the granite was nearly solid. This is why it differs from the adamellite and why it forms the outer layer and the last granite to solidify. He also pointed out that it had very few pegmatites and a lack of garnets, which suggests there was very little water present in the magma.

We next went on to look at some dark limestones in a quarry just outside Galway. We looked for fossils but did not find any of significance. From here we went on

to the last quarry of the day - the Galway Roadstone Quarry. Here there was a dacite dyke cutting Murvey Granite. We also saw some amphibolite facies rock with hornblende and garnets. Fatigue had caught up with me by then - I stopped taking notes!

Our last stop of the day was at the Geology Department of University College, Galway. Here Paul showed us their museum, which is undergoing a gentle and slow restoration. It has been almost untouched since Victorian times and is of interest for that reason if no other. We spent an intersting time looking at both the exhibits and some unusual documents.

We thanked Paul for his help and that evening treated him to what, through various circumstances, seems to have been our staple diet in Galway, a Chinese meal. All of us sat down, after some arguments with the waiters, at one long table and enjoyed a pleasant evening. It was rounded off at our hotel by a majority of the party finishing the various bottles that had been collected during the week. We then helped Paul into a taxi, but not before he had fulfilled a life time's ambition and done his imitation of a certain Belgian statue on the parapet of one of the canal bridges in the middle of Galway!

The next day we left Galway to drive back to Dublin to catch the ferry home, some of us feeling a little the worse for wear! On the way across we were able to observe the heavily glaciated, low, flat peat country of central Ireland, the road for much of the way running along the top of an esker. Back at Dublin we returned to the top of Killiney Hill to admire the view, a sight we had been denied on our first day because of the mist. Then it was down to the ferry and, after our goodbyes, back along our separate ways home, having enjoyed a very happy week. I think this is an ideal opportunity to reiterate our thanks to all our leaders in Ireland and also to Malcolm Roberts for all the work he put into organising so superb a trip. If this account has got you interested in Ireland a return trip is planned for 1981.

Roger Levoir

More Deviltry

Felsite Area where most accidents occur

Fore Deep Usually found as a more or less linear deposit of geologists - a 'bar'

Gravity Transport Quickest way down

Gravity Collapse Structure Result of travelling by gravity transport

Jasper A male person (knighted) noted for his somewhat indecisive female companions

Thanks Pat. Are there any other devils hiding among the rocks out there?